2334 (1) pest infestation

(2) insect pest control

(3) ~~pests~~ (4) grain storage

(5) insecticides

(6) fumigants

(7) insects (8) insect pests

(9) fumigation

(10) isotope tracers

(11) pest infestation laboratory

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PEST INFESTATION RESEARCH

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

REPORT OF THE PEST INFESTATION RESEARCH BOARD

WITH THE REPORT OF THE
DIRECTOR OF PEST INFESTATION RESEARCH

FOR THE YEAR 1949

LONDON: HIS MAJESTY'S STATIONERY OFFICE
1951

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31st December, 1949

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REPORT OF THE
PEST INFESTATION RESEARCH BOARD
FOR THE YEAR 1949

To the Lords of the Committee of the Privy Council for Scientific and Industrial Research

IAY IT PLEASE YOUR LORDSHIPS,

VE, the Pest Infestation Research Board, beg leave to present a report on our roceedings during the year 1949. We append the report of the Director of 'est Infestation Research for the same period.

RESEARCH PROGRAMME

The chief problem of policy with which we have been concerned has been nentioned in our last report, viz., to ensure that the scientific effort available t the Pest Infestation Laboratory is being applied in the most effective way n the country's present economic circumstances. This problem is largely ne of deciding the most effective balance between the practical experimentation ecessary for the solution of urgent day-to-day problems and the longer-range esearch without which it is impossible for the Laboratory to develop new leas or to keep abreast of progress in the sciences which build up its ability o serve industry.

In establishing this balance we have to try to meet both these needs with esources which, under present conditions, are necessarily limited, especially n staff. We are glad to be able to report that in this respect, at least, there re some signs of improvement which we warmly welcome. In the circumances, we feel that the Laboratory has achieved very good progress.

The following summary of some of the more outstanding items in the current rogramme of research indicates the widely different lines of investigation hich are being followed.

TUDY OF THE PHYSICAL CONDITIONS WHICH PREVENT THE DEVELOPMENT OR URVIVAL OF THE DIFFERENT SPECIES OF INSECTS AND MITES

The different developmental stages of insects vary very much in their resistance o extreme physical conditions, such as heat, cold or drought. A climate hich is too rigorous for the most sensitive stage will effectively prevent the evelopment of a population over a period of years, and a full understanding f the possibilities of such natural control is clearly of great practical importance. milarly it is valuable to know what conditions are necessary to destroy even ne most resistant stages of the pests, for if these conditions can be achieved omplete disinfestation will result.

CONTROL OF BLOWFLIES IN SLAUGHTER-HOUSES

Experimental work during 1948 led to the application, as a routine measure, of DDT dust to the refuse and vegetation at a large slaughter-house in London. This treatment, combined with systematic storage and collection of refuse, has been continued throughout 1949, with the result that, except on one occasion, linked with a breakdown in the collection system, no larvae have been found on the premises. In contrast to this, from one heap of untreated refuse a little under $\frac{3}{4}$ cwt. in weight, exposed to fly attack for only three days in 1948, no fewer than 26,000 blowflies emerged. A considerable measure of success may therefore be claimed for this work.

FUMIGATION OF BULK GRAIN IN FLOOR STORAGE

The disinfestation of very large quantities of grain stored in bulk on floors has recently become a problem of increased importance. Treatment with methyl bromide applied above the grain surface was found to be yielding rather variable results, so a careful investigation was made of the factors affecting the distribution and movements of the fumigant when applied in this way. It has been shown that an important, but perhaps uncontrollable, factor affecting gas distribution is the slow movement of air through the bulk, due largely to the existence of temperature gradients within the grain.

REACTION OF METHYL BROMIDE WITH FOODSTUFFS

The treatment of large quantities of foodstuffs with chemicals such as fumigants raises a number of questions regarding the possible effect on the food itself. No large-scale treatment is ever put into practice without first ensuring that no toxic residues will remain, but a great deal of careful biochemical work is necessary before a full understanding can be reached of the detailed reactions of the chemical with the constituent fractions of the foodstuff being treated.

Such work is important, not only for its own sake, but also because it may throw light on the mode of action of the insecticide, to insects no less than to man. Biochemical work, combined with the use of radioactive isotopes, is already beginning to provide information on these very interesting problems.

OVERSEAS LIAISON

We are glad that it has been possible for three of the senior staff to go overseas on official visits. At the request of the Colonial Office, Mr. T. A. Oxley undertook a four months' survey of grain storage in Central and East Africa. It was hoped that conclusions drawn from the survey would be applicable to British Colonial territories generally. To some extent it appears that conditions in the surveyed area are not typical, particularly of the dampest areas of the Colonies, but many conclusions which may have a wider application could, nevertheless, be drawn. The Report of the Survey is to be published in the Colonial Office Research Series

At the invitation of the British Council, the Director spent six weeks in the Middle East, lecturing on different aspects of stored products infestation, and studying at first hand local problems of infestation and the methods used for their solution. The majority of the time was spent in Egypt, but visits were also made to Iraq, Lebanon and Syria.

Dr. E. A. Parkin visited Canada and the United States from 6th September to 24th November, 1949, to discuss problems of the control of stored products and household insects with special reference to the use of contact insecticides.

Dr. Parkin attended the 2nd International Congress of Crop Protection, held in London from 21st to 28th July, 1949, as an official delegate from the Department.

Even though the regular programme of work of the Laboratory has inevitably been affected thereby, the knowledge of conditions overseas and the stimulus provided by such visits, makes them eminently worth while, since the experience gained will undoubtedly influence the future work of the Laboratory.

LIAISON WITH OTHER DEPARTMENTS

MINISTRY OF AGRICULTURE AND FISHERIES (INFESTATION CONTROL DIVISION)

Much of the work of the Laboratory is directed towards the solution of problems confronting the Infestation Control Division of the Ministry of Agriculture and Fisheries, and the Laboratory, in turn, is largely dependent upon the Division for information about these problems. Collaboration between the two organizations is therefore a necessity, and we are glad to record that it has continued in an effective and intimate form.

The appointment of Dr. J. W. Evans, who is in charge of the scientific work of the Division, as an Assessor to the Board is providing a most valuable additional link between the Division and the Laboratory.

COLONIAL OFFICE

As already reported, the Laboratory is represented by the Director on the Stored Products Research Sub-Committee of the Colonial Office. Mr. R. W. Howe, one of the senior entomologists at the Laboratory, is a member of the team of scientists sent by the Colonial Office to West Africa to investigate and organize the control of the infestation of stored foodstuffs in that part of the world.

In view of the direct bearing of the Laboratory's work on Colonial problems, it has been agreed between the Colonial Office and the Department that a Colonial Liaison Officer be attached to the Laboratory. It will be the duty of this officer to act as a channel through which enquiries from the Colonies on problems of infestation and grain storage will be received and information from the Laboratory will be disseminated to the Colonies. He will also acquaint himself, at first hand, with conditions in the Colonies. We welcome this arrangement as a very valuable step forward which should be of benefit to the Colonial Governments and to the Laboratory.

OTHER CONTACTS WITH OFFICIAL BODIES

During 1949, help by advice or discussion has also been given on a variety of problems concerning insect infestation to the Agricultural Research Council, Colonial Office, War Office, Ministry of Works, National Coal Board, Board of Trade and the Central Office of Information.

ACCOMMODATION

We are glad to note that improvements to existing laboratory buildings are either completed or are in process of completion, notably for the extension of constant temperature and humidity rooms. We are especially pleased to learn that plans have been prepared for two new laboratory buildings. One of these will provide proper accommodation for the Isotope Tracer work of the Laboratory; the other will relieve the extreme congestion of workers in existing buildings; it will also allow for a little of the expansion of the Laboratory which your Lordships have already approved, and particularly, it will provide some accommodation for visiting scientists from overseas.

ORGANIZATION OF THE LABORATORY

In order to meet the needs of the expanding work of the Laboratory, a new Isotope Tracer Section has been formed. This was foreshadowed in our Report for 1948, and has already made rapid strides in the application of radiochemical techniques to the work of the Laboratory, especially in problems concerned with fumigation and with the retention of insecticides by foodstuffs.

We consider it appropriate that this work, so specialized in its nature, should be undertaken in a separate section, but we are glad that this administrative segregation will in no sense affect the close collaboration with other Sections, which is vital to the health of the Laboratory as a whole.

J. L. SIMONSEN,
Chairman

May, 1950.

REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH FOR THE YEAR 1949

BIOLOGY

The work of the Biology Section during 1949 falls into three categories; the study of physical limits, of life-histories, and of habits and behaviour.

The following sections all deal with practical investigations, In addition to these, work is in progress on a survey of the physical ecology of the major storage and domestic pests. This involves the summarizing as far as possible in convenient graphical form, of what is known of the power of increase of each species under various conditions, and more particularly its physical limits. This information is being linked with the geographical distribution of the species concerned, and its original habitat, as far as this is known.

Physical Limits

For an understanding of the present and potential distribution of pests it is clearly important to know what physical conditions are necessary for the survival and for the complete development of each species. The physical limits for complete development are the most extreme temperatures and humidities in which even the least resistant stage in the life-cycle can continue its development. The physical limits for survival are those beyond which even the most resistant stages are killed. The work along these lines comprises (in the order given below) laboratory studies upon several species, overwintering experiments with a number of species in unheated buildings, and experiments on the control of clothes moths by heating.

LABORATORY DETERMINATION OF PHYSICAL LIMITS

Ptinus tectus Boield.

Further work on the Australian Spider Beetle has been devoted to finding the survival period under conditions in which this species fails to complete its life-cycle.

The following examples from the data refer to the most resistant stage, i.e., the adult when the temperature is low, or the third-stage larva when the temperature is about 20°C. or higher. They represent the survival periods of the most resistant individual in a sample of approximately 20.

Low temperature:	1·5° to +0·5°C. (70% relative humidity), 54+ days.
High temperature:	30°C. (70% relative humidity), 83 days.
	35°C. (70% relative humidity), 9 days.
Low humidity:	20% relative humidity (10°, 20°, 30°C.), 84+, 52 and 51 days.
	40% relative humidity (30°C.), 50 days (*H.D. Burges, K.I. Street*).

Tribolium castaneum Herbst

The Rust-red Flour Beetle is an insect adapted for life in warm climates, and does not overwinter in Britain in unheated buildings. Laboratory experiments have indicated that it cannot complete its development at temperatures much below 20°C.

Nevertheless, eggs were laid at lower temperatures down to about 10°C.; at this temperature, adults survived up to 12 weeks and large larvae up to 20 weeks. The majority of adults and large larvae survived exposure to 0°C. for at least a day, though all were killed within a week; sublethal exposure of adults to this temperature did not reduce the subsequent egg-output, though it seemed to reduce the viability of the eggs. (*H. D. Burges*).

Trogoderma granarium Everts

At the request of the Pest Infestation Survey (Colonial Office) in Nigeria, an investigation is being made into the effect of high humidities on the rate of breeding of the Khapra Beetle, which attacks stored ground-nuts, etc.

Results to date indicate that high humidities, such as 90 and 100 per cent, do not necessarily impede breeding very much, but that when the nuts become very mouldy and rotten *Trogoderma* suffers a high mortality. (*H. D. Burges, Miss J. E. Currie*).

Tenebrio molitor L.

The Yellow Mealworm Beetle is adapted to cooler conditions than the related pest, *T. obscurus* Fab. It readily overwinters in unheated buildings in Britain.

Laboratory experiments and information from the literature indicate that the highest temperature at which complete development can take place is between 32° and 34°C., and the lowest between 13° and 20°C. Larvae cannot develop at very high humidity, probably because of extensive mould growth; the highest humidity at which development can be complete is between 85 and 95 per cent relative humidity and the lowest between 20 and 40 per cent relative humidity. The large larva is the stage most resistant to adverse conditions; it can survive one hour at 42°C. and 100 per cent relative humidity, one hour at 43°C. and 0 per cent relative humidity, and 24 hours in all humidities at 38·5°C.; it is killed in less than 3 weeks at −5° to −10°C. (*H. D. Burges, Mrs. U. Harding*, (*W. A. Carter, Miss M. P. Butler*)).

Ephestia elutella Hueb.

The physical limits at which complete development of the Cocoa Moth can take place have been determined approximately, and this work is to be continued.

The upper limit of temperature is 35°C. at favourable humidities and probably slightly lower under dry conditions; the lower temperature limit is between 5° and 15°C. The upper humidity limit is between 80 and 95 per cent relative humidity, varying slightly with temperature, and the lower limit between and 10 per cent relative humidity.

The large larva, which is probably the stage most resistant to heat, survives less than 9 days at 40°C. (*H. D. Burges, Mrs. U. Harding*).

Ephestia cautella Wlk.

In conjunction with overwintering experiments, the low temperature limi

of the Dried Currant Moth are being examined in the laboratory. The results to date indicate the exposures to low temperatures necessary to prevent the subsequent development to maturity of the large larvae, probably the most resistant stage. These exposure periods are 6 weeks at 5°C., 5 days at 0°C., or one day at —7°C. (*H. D. Burges, Mrs. U. Harding*).

Tineola bisselliella Hummel

The high temperature limits for the survival of the common Clothes Moth have been determined in a series of experiments on each of the developmental stages. While some larvae may survive about a week at 37°C., all stages are killed within 4 hours at 41°C. and relative humidity 70 per cent. (Fig. 1).

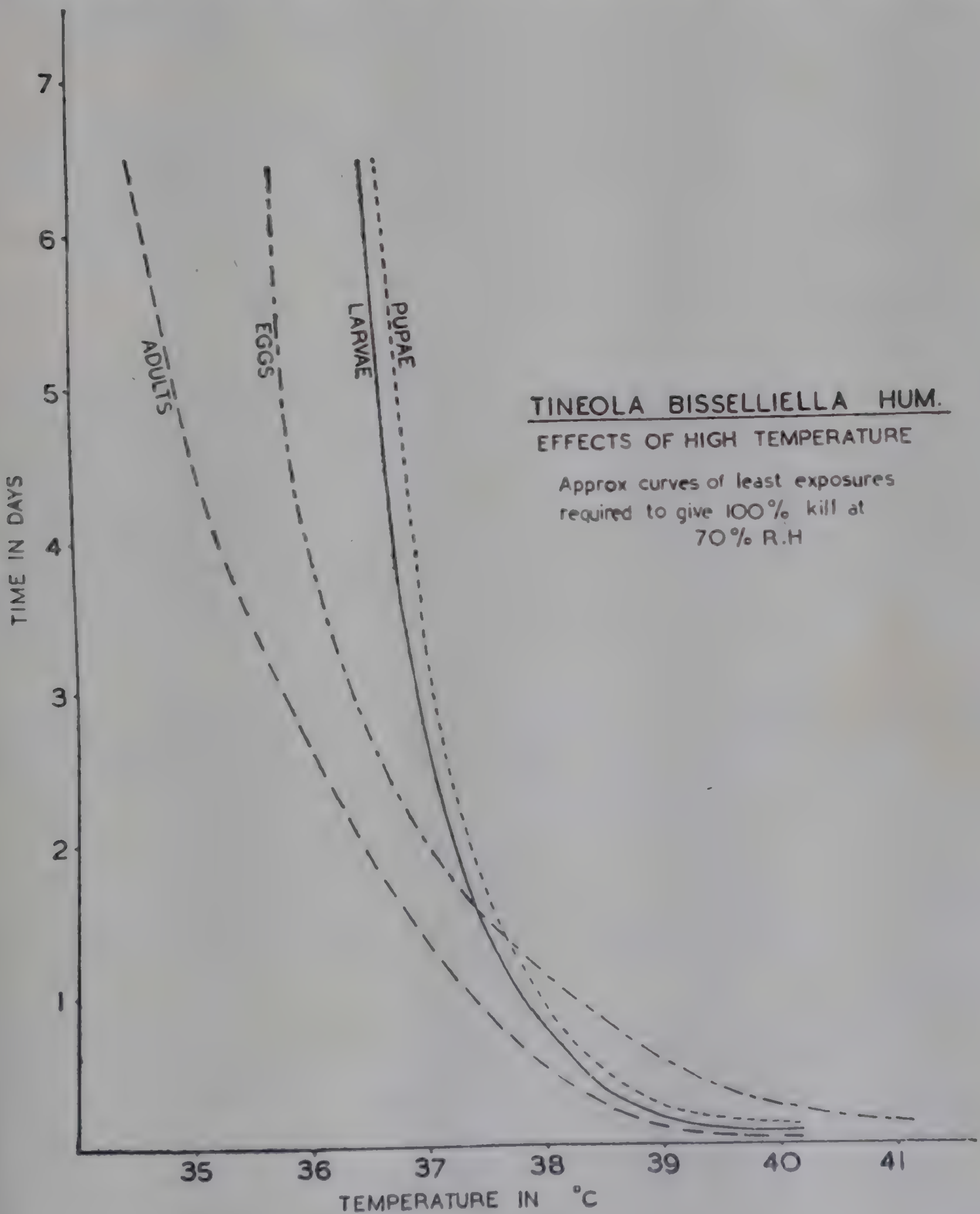


Fig. 1

The practical application of this knowledge is discussed in a later paragraph

A briefer investigation has been made of the degree of cooling required to reduce damage by the larvae, i.e., feeding, to a negligible level, and also of the

lethal effects of such treatment. The rate of damage (measured by the weight of faecal pellets produced) depended both on the temperature and on the stage of development of the larvae. A little feeding occurred at 5°C. and many of the older larvae survived, though they practically ceased feeding after 5 weeks. At a temperature of 0° to 2°C., only negligible damage was done and this ceased after 3 weeks, though a few of the older larvae survived much longer. (*Miss S. G. Rawle*, *Miss G. M. Skellon*).

Tyroglyphus farinae L.

A series of experiments to determine the physical limits for complete development of the Flour Mite is nearly completed. The maximum temperature for complete development is about 31°C.; at this temperature the egg mortality is extremely high even at 90 per cent relative humidity, and it is not yet certain whether fecund females can be produced.

The low humidity limit for complete development lies between 60 per cent and 62·5 per cent relative humidity at 15° and 20°C.; at 60 per cent relative humidity or below, even adult mites usually die within 2 days, and eggs do not hatch. At much higher or lower temperatures, the humidity threshold is higher, e.g., about 70 per cent relative humidity at 30° and at 5°C.; at 5° many eggs hatch but the mortality of larvae is very high.

The resistance of the eggs to periods of exposure at 50 per cent relative humidity has also been investigated. It is found that newly laid eggs (less than 24 hours old) are the most resistant to this treatment, and become less resistant as they age. Eggs are more resistant than adults. Even after exposure for 6 days, 2 per cent survived and developed to the adult stage on removal to 90 per cent relative humidity. Eggs taken from culture cells at 65 per cent relative humidity were more resistant to the drying treatment than those from 90 per cent relative humidity. (*A. M. Cunnington*, *Miss J. M. Mitchell*, *Miss S. R. Wiley*).

OVERWINTERING TESTS IN UNHEATED BUILDINGS

The question whether or not a particular pest can overwinter in Britain is one of obvious practical importance. With many species the question is essentially complicated, and the answer depends on such factors as the severity of a particular winter, the nature of the building and of the infested material. In these cases it is necessary to observe their survival or elimination under various combinations of the factors referred to above, with the aim of generalizing the results as data from these experiments and from laboratory tests are accumulated.

Special attention is being given to the overwintering powers of *Ephestia cautella* Wlk., since the Dried Currant Moth is reported to overwinter only occasionally in unheated buildings. Cultures were put out, in late autumn, in various types of unheated buildings, to be examined periodically throughout the winter. These experiments are supplementary to a larger series being conducted by Mr. G. A. Brett and other officers of the Infestation Control Division of the Ministry of Agriculture and Fisheries.

In addition, the insectary staff have put out cultures of 49 species in a small unheated building, and these are being observed at intervals. In procedure, this is essentially a repetition of an earlier experiment by G. H. Mansbridge in 1936, but it is hoped to collect a series of records, in this and subsequent

winters, which will show more precisely what conditions each species can withstand.

The overwintering experiments have emphasized the need for a clearer knowledge of the physical conditions prevailing in various types of building, in relation to the outdoor conditions. Useful information of this sort will emerge from the comparison of thermohygrograph records from the above experiments with the official meteorological records. (*H. D. Burges*, *Mrs. U. Harding*, *Miss B. E. Adamson*, *Miss E. A. Myerscough*).

Life-Histories

Under this heading comes the study of rates of development, of egg-output and of mortality under various environmental conditions. For reasons referred to in last year's report, some of this work is being designed to give results in a form suitable for the calculation of net rates of population increase. Certain results have drawn attention to the variability of the species concerned, leading to the conclusion that, in some instances, realistic information can be got only from a number of parallel experiments on different stocks of the species.

Work on the moth *Hofmannophila* has shown the great importance of a diapause or resting stage in the life cycle of certain insects, and has raised problems concerning the physiological bases and the ecological significance of diapause.

Hofmannophila (=*Borkhausenia*) *pseudospretella* Staint.

Work on the life-history of the Brown House Moth has been completed and an account of it is in the press. It has been found that this species requires a high humidity for the completion of its development, for the larvae fail to mature if it is much below 80 per cent relative humidity. On the other hand, the eggs, pupae and diapausing larvae are extremely resistant to desiccation; even at nearly zero humidity a few eggs develop and hatch, and diapausing larvae live up to 3 months.

Larvae were reared successfully on a wide range of animal and vegetable materials, some predominantly carbohydrate, some almost entirely protein; the most rapid development was achieved on a diet of dead adults.

Even when the food and other conditions are standardized, the total development period is very variable, because of the variability in the length of the larval diapause. Thus at 25°C. and 90 per cent relative humidity, the total development periods of individuals reared on "middlings" varied between 152 and 266 days and at 20°C. and 90 per cent relative humidity it varied between 192 and 440 days. Under field conditions, the development period was about 12 months.

After spinning their cocoons, all fully-grown larvae except those reared at low temperatures passed into a diapause phase. Such larvae undergo an extra moulting of the cuticle and then assume a characteristic appearance. This quiescent phase persists for a period which depends largely on the temperature at which the larvae have been reared.

The number of eggs laid by a female was found to depend largely on her weight at emergence, and varied between 106 and 657 at 25°C. and 70 per cent relative humidity. The number was reduced at low temperatures and at low humidities. No females lived longer than a few weeks.

The only important natural enemy found was the predatory mite *Cheyletus eruditus* Schr., which destroyed numbers of eggs and young larvae. (*G. E. Woodroffe*).

Endrosis lactella Schiff. (=*E. sarcitrella* L.)

Work on the life-history of the White-shouldered House Moth was carried on simultaneously with that on *Hofmannophila*, and a comparative study is in the press. Though it sometimes occurs in houses, *Endrosis* is best known as a minor pest of grain, seeds, and other stored products.

Like those of *Hofmannophila*, the feeding larvae of *Endrosis* require a high humidity, and do not develop successfully at much below 80 per cent relative humidity. Eggs, larvae and pupae, like those of *Hofmannophila*, all failed to survive at a temperature of 30°C.

Larvae developed most rapidly on a diet of dead moths. At 90 per cent relative humidity, the mean development period, egg to adult, was 235 days at 10°C. and 62 days at 25°C. There is no diapause in this species.

Whereas *Hofmannophila* produced about equal numbers of each sex, a mass culture of *Endrosis* on grassmeal produced 23 times as many females as males. The longevity of adult females varied with the physical conditions, up to about 10 days at the lowest temperature tested (15°C.). The number of eggs laid depends partly on the initial weight of the female; this varied from 2·9 to 9·4 mg., and the egg output from 14 to 231. (*G. E. Woodroffe*).

Tyroglyphus farinae L.

In continuation of the work on the life-history of the Flour Mite, described in last year's report, the mortality at various temperatures and humidities within its range of viability has been determined. Low mortalities, always below 30 per cent, often below 10 per cent, have been found in experiments at 15°C., and at 20°C. at 80 per cent and 90 per cent relative humidity. High mortalities, often above 50 per cent, have been found at 25°C., and at 20°C. at 70 per cent relative humidity.

Wide variations often occurred between repeated experiments. It is thought probable that an important cause of this variability was the growth of different species of fungi and bacteria on the food material in the breeding cells, particularly at high humidity. (*A. M. Cunnington, Miss J. M. Mitchell, Miss S. R. Wiley*).

Habits and Behaviour

CARPET BEETLES

Besides being taken into account at all stages of the study of any pest, its habits and behaviour sometimes require special attention. This is so in the present state of our knowledge of clothes moths and carpet beetles, particularly the latter, since there is relatively little information on their movements into and about houses, on the factors governing their choice of sites for egg-laying, and so on.

Together with the preliminary work of collecting and identifying carpet beetles, chiefly *Anthrenus* spp., and their larvae wherever they are to be found, a start has been made on a laboratory study of their behaviour, beginning with the temperature preferences of the larvae. (*Miss G. M. Skellon*).

GRAIN STORAGE

Visits abroad

From October, 1948, to mid-February, 1949, Mr. T. A. Oxley was loaned to the Colonial Office in order to make a survey of grain storage in Central and East Africa.

The survey revealed that losses of grain in storage are very heavy, and that there is little knowledge in the colonies of the best methods of storage or of the scientific principles which underlie all such methods. One major recommendation, therefore, was that arrangements should be made for the fullest possible provision of information from the Pest Infestation Laboratory (and other Laboratories working on similar lines) to all Colonial Territories. This is to be met by the appointment of a Colonial Liaison Officer at the Laboratory.

One result of the survey has been that the Laboratory has received a considerable number of enquiries from the Colonies. Some time has also been spent in the examination of commercially available grain drying and handling machinery, partly from the point of view of its suitability for Colonial use.

Impregnated Wood for Grain-Drying

Owing to shortage of staff, little progress has been made with the development of the process for drying grain by impregnated wood, which was described in the last Annual Report. It has been found desirable to use wood in the form of flat chips about 1·6 mm. thick rather than more or less equidimensional blocks, and 30 lb. of such chips have been prepared for experimental purposes by the Forest Products Research Laboratory of the Department. (*T. A. Oxley, J. P. Heslop*).

Sub-epidermal Fungi of Wheat Grains

SURVEY OF WORLD DISTRIBUTION OF THE FUNGI

The survey begun last year on the world distribution of the sub-epidermal fungi in wheat grains has now been completed, and a paper prepared for publication. The results show that the fungi are world-wide in distribution. Of 278 samples examined from 89 sampling points, only 5 varieties from 5 places had no internal fungus. These were all from fairly dry areas—Chile, Mexico, N. Rhodesia, South Dakota, and Turkey. The difference in amount of fungus from different localities was shown to be correlated more closely with climatic factors than with differences in variety, type of wheat, etc., the mycelium being more commonly found and better developed in samples from relatively damp climates. There was found to be a fairly close correlation ($r=0{\cdot}83$: $P<0{\cdot}001$) between amount of fungus and atmospheric relative humidity in the few weeks before harvest, the period during which internal fungi are first seen in the grains. There is a slight inverse correlation ($r=-0{\cdot}59$; $P<0{\cdot}01$) between amount of mycelium and mean temperature in the fortnight before harvest.

IDENTIFICATION OF THE FUNGI

The several types of hyphae present suggest that there are a number of different species of sub-epidermal fungi. During the year, methods of culturing the internal mycelium have been investigated, and preliminary isolations indicate

that species of *Alternaria*, *Cladosporium*, *Fusarium* and *Stemphylium* are among the fungi found beneath the epidermis. The recent appointment of a mycologist to the Section will expedite this work.

PRODUCTION OF FUNGUS-FREE WHEAT

The two methods of producing fungus-free wheat, viz., by spraying with fungicidal or fungistatic substances or by growing individual ears in desiccator chambers, which were successfully developed during 1948, were applied on a larger scale in 1949. Only one spray substance was used, 8-hydroxy quinoline sulphate, this having been the most successful of the substances previously investigated, and virtually fungus-free grain was obtained in the five varieties treated (Atle, Bersee, Holdfast, Squareheads Master, and Vilmorin 27). The grain produced by development in desiccator chambers was completely free of internal fungi.

Owing to the exceptionally dry summer of 1949, the untreated wheat had very much less internal mycelium than usual, there being only about one-third the amount normally present and expected from the typical climate of the British Isles. As mentioned in last year's report, the internal mycelium is not present until a comparatively late stage of maturity, when the grains have almost reached final dry weight and have begun to dry out. Advantage was taken of the extremely dry season of 1949 to harvest some untreated wheat prematurely, just before internal fungus was found. This was ripened off indoors at a humidity of approximately 50 per cent, and the resultant grain was completely free from sub-epidermal fungi but was otherwise normal (as regards dry weight, germination capacity, etc.). (*Miss M. B. Hyde*, *D. Budd*).

INSECTICIDES

The Section has covered a wide field of work during 1949, though staff changes have in some cases restricted the rate of progress.

Statistical Aspects of Insecticidal Action

Following the publication, in co-operation with the Mathematics Division, National Physical Laboratory, of a paper on statistical aspects of the independent joint action of insecticides, a second paper is being prepared in which methods are described for discovering whether a mixture is as toxic as predicted on the hypothesis of independent action, and the methods are illustrated by data from laboratory tests. In these tests Flour Beetles, *Tribolium castaneum*, were sprayed with solutions of pyrethrins, DDT, and gamma-BHC, alone and in pairs. The mixture of pyrethrins and gamma-BHC killed a much higher proportion of these beetles than was predicted on the hypothesis of independent joint action. (*P. S. Hewlett*).

Sprays for Use against Warehouse Insects

The very promising results obtained with pyrethrum and gamma-BHC mixtures used in the statistical tests just mentioned coincided with a request from the Infestation Control Division, Ministry of Agriculture and Fisheries, for suitable formulations of the mixed insecticides for practical use. Because the available laboratory data were confined to tests with the Flour Beetle,

Tribolium castaneum, experiments have been made with a few other species of stored product insects. The results obtained were not so encouraging as with *T. castaneum*, because the admixture of pyrethrins adds little to the lethal effect of the gamma-BHC. Nevertheless, the presence of pyrethrins is advantageous in that they impart a quick knock-down effect to the mixture. It is hoped shortly to be able to recommend formulations for oil sprays.

An investigation has also been started on the efficacy of various mixtures of piperonyl butoxide and pyrethrins in sprays. This substance is said to enhance both the toxicity and stability of pyrethrins and to have such a low mammalian toxicity that it can be employed in insecticides intended for use in the treatment of foodstuffs. Tests already carried out have shown that piperonyl butoxide, which is itself only slightly toxic, greatly intensifies the lethal effect of pyrethrins on the Flour Beetle, *Tribolium castaneum*, and the Granary Weevil, *Calandra granaria*, but more experiments must be done before the question of increase in stability can be answered and economic formulations worked out. (*P. S. Hewlett, Miss B. Clayton*).

Relative Resistance of Stored Product Insects to Insecticides

Some additional exposures of beetles and their larvae to a 5 per cent DDT dust have been made, but it has not yet been possible to analyse the results fully.

An interesting observation made in the course of this work was that, whereas Khapra Beetles, *Trogoderma granarium*, showed relatively little resistance to the DDT dust, the larvae were very highly resistant to its action. This finding was of considerable interest in view of the frequent occurrence of this insect in maltings in the United Kingdom and its recent increase in importance as a pest of ground-nuts in store in West Africa. Some preliminary tests have been made to evaluate the resistance of the larvae to other insecticides, used as dusts, direct sprays (in a heavy oil base), or films deposited on grain sacking. Pyrethrum powder (0·9 per cent pyrethrins) and 4 per cent BHC dust affected the insects fairly quickly but were slow to cause death; alumina was also slow in action at 25°C. and 70 per cent R.H. but acted much more quickly at 30°C. and 30 per cent R.H., as would be expected; 10 per cent DDT and felspar dusts were ineffective. As a direct spray, 1·3 per cent pyrethrins in a heavy oil was more effective than 1·0 per cent gamma-BHC. In general, these results showed that *T. granarium* larvae are extremely resistant to the insecticides so far tried against them. (*E. A. Parkin, Miss B. Clayton*).

Transfer of DDT from Treated Surfaces to Foodstuffs

The transfer of DDT from impregnated sacking to five selected foodstuffs was dealt with at some length in the Report for 1948. A full account of this investigation has now been published. Larger quantities of DDT than expected were transferred to some foodstuffs, and the extent of likely contamination of foodstuffs by other types of application of DDT immediately became of great interest. As too much work would have been involved in testing all combinations of the DDT treatments with several types of foodstuff, the investigation has been confined to wheat. Experimental exposures of wheat under conditions simulating bulk storage and bag storage in contact with DDT dusts

and residual sprays on cement and wood have been made and samples taken after 10 weeks. Loss of staff has held up analysis of these samples for DDT content but a start has now been made. (*E. A. Parkin, A. A. Green*).

Mothproofing Tests

The Pest Infestation Laboratory is taking part with three other laboratories in an attempt to work out a satisfactory technique for assessing mothproofing efficiency. There has been considerable discussion in committee of the advantages and disadvantages of the published methods of test, and a certain amount of experimental work is being undertaken to provide more data on some points, but the data so far obtained in the different laboratories have been at times awkwardly at variance. It has therefore not yet been possible to come to final agreement upon any of the major points to be decided, namely, (*a*) the method for producing suitably standardized larvae of the test insect (the Webbing Clothes Moth, *Tineola bisselliella*); (*b*) the method of exposure of the treated material to the larvae; or (*c*) the assessment of damage, with particular reference to the problem of how much damage shall be admitted on a sample to be considered satisfactorily proofed. (*E. A. Parkin, Mrs. P. J. Maycock*).

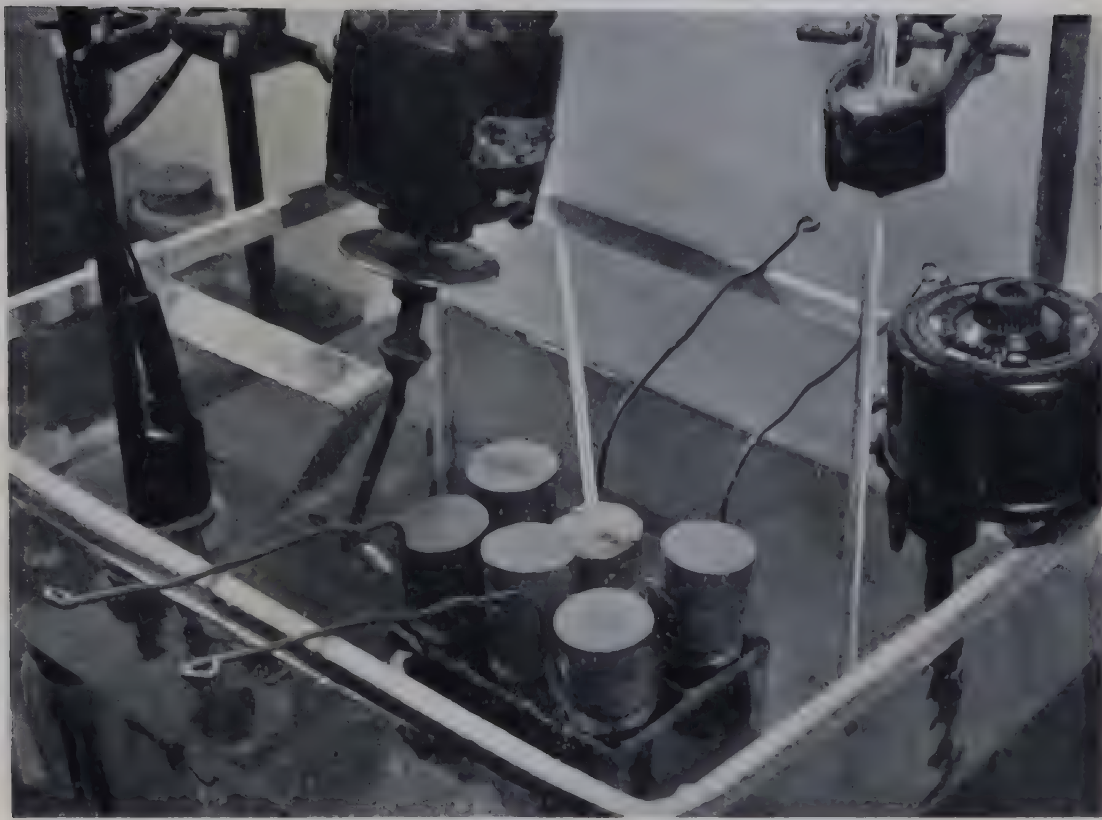
Attractants and Repellents

An investigation has been started to attempt to discover attractants and repellents for stored product and/or household insects. Since attractants and repellents tend to be highly specific, it is necessary to consider each species of insect as a special problem.

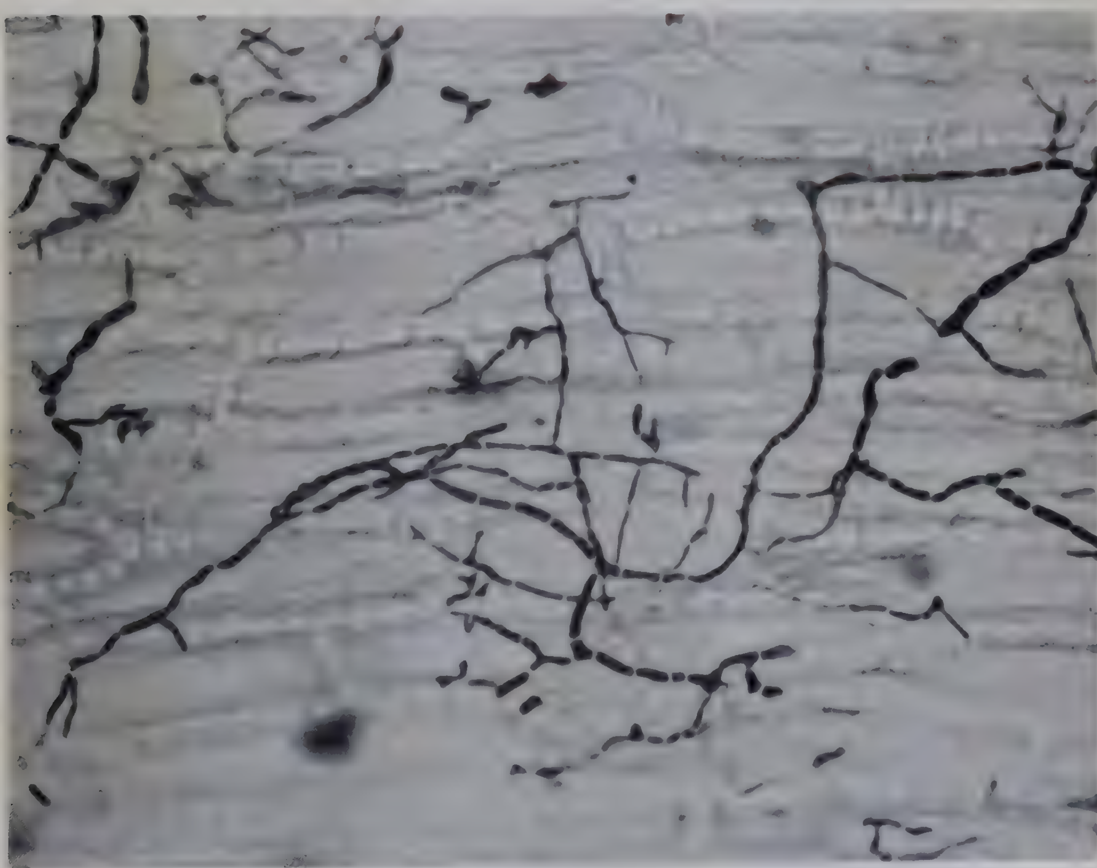
An apparatus is being constructed to test the olfactory response to different chemicals of the Greenbottle Fly, *Lucilia sericata*, one of the species of blowflies commonly infesting slaughter-houses. Flies passing up the vertical limb of a glass T-tube are able to make their choice between two air streams, one of which carries the odour under test, flowing along the horizontal side-arms. Preliminary tests of the apparatus have led to modifications which are now being incorporated.

Some preliminary experiments have been made with simple apparatus constructed on the fly-trap principle. Fresh meat was put in as a bait and one trap was treated with the chemical under test. Both traps were stood in a chamber containing free-flying Greenbottles. A number of essential oils have been tested and most of them found to be good repellents, in that few or no flies entered the treated trap. The method does not distinguish between olfactory and gustatory effects, but may be useful as a primary screening test to avoid including completely unsatisfactory compounds in more detailed tests.

As part of this investigation it has been necessary to secure a steady supply of experimental insects bred under known, standard conditions. A method has been adopted in which eggs are laid by caged flies on small pieces of waste meat and the larvae hatching from them are reared on a wet medium of toppings, grassmeal, yeast, dried malt, casein, and dried blood. Although the larvae mature and pupate on this medium and the resulting flies are fertile, the addition of a little meat to each culture greatly improves their size and apparent vigour. (*E. A. Parkin, Mrs. P. J. Maycock*).



(a) Controlled-temperature water bath used in experiments on high temperature limits of the clothes moth. The insects were placed with food material in the stoppered tubes (*see p.* 7)



(b) Photomicrograph of Mycelium on the inner surface of the epidermal layer of a wheat grain (*see p.* 11)

PLATE 1

(a) Eggs ; young larvae

(b) Adults, male (left) and female (right)

(c) Young larva attacked by the mite *Cheyletus eruditus* Schr.

THE BROWN HOUSE MOTH *Hofmannophila pseudospretella* (STAINT)

PLATE 2

(a) Fully grown larva (left) ;
diapausing larva (right)

(b) Bin of infested dried grass

THE BROWN HOUSE MOTH *Hofmannophila pseudospretella* (STAINT)

PLATE 3

(a) Determining the number of beetles killed by exposure to insecticides applied to filter papers. The glass rings confining the insects allow easy examination under a low-powered binocular microscope (*see p.* 12)

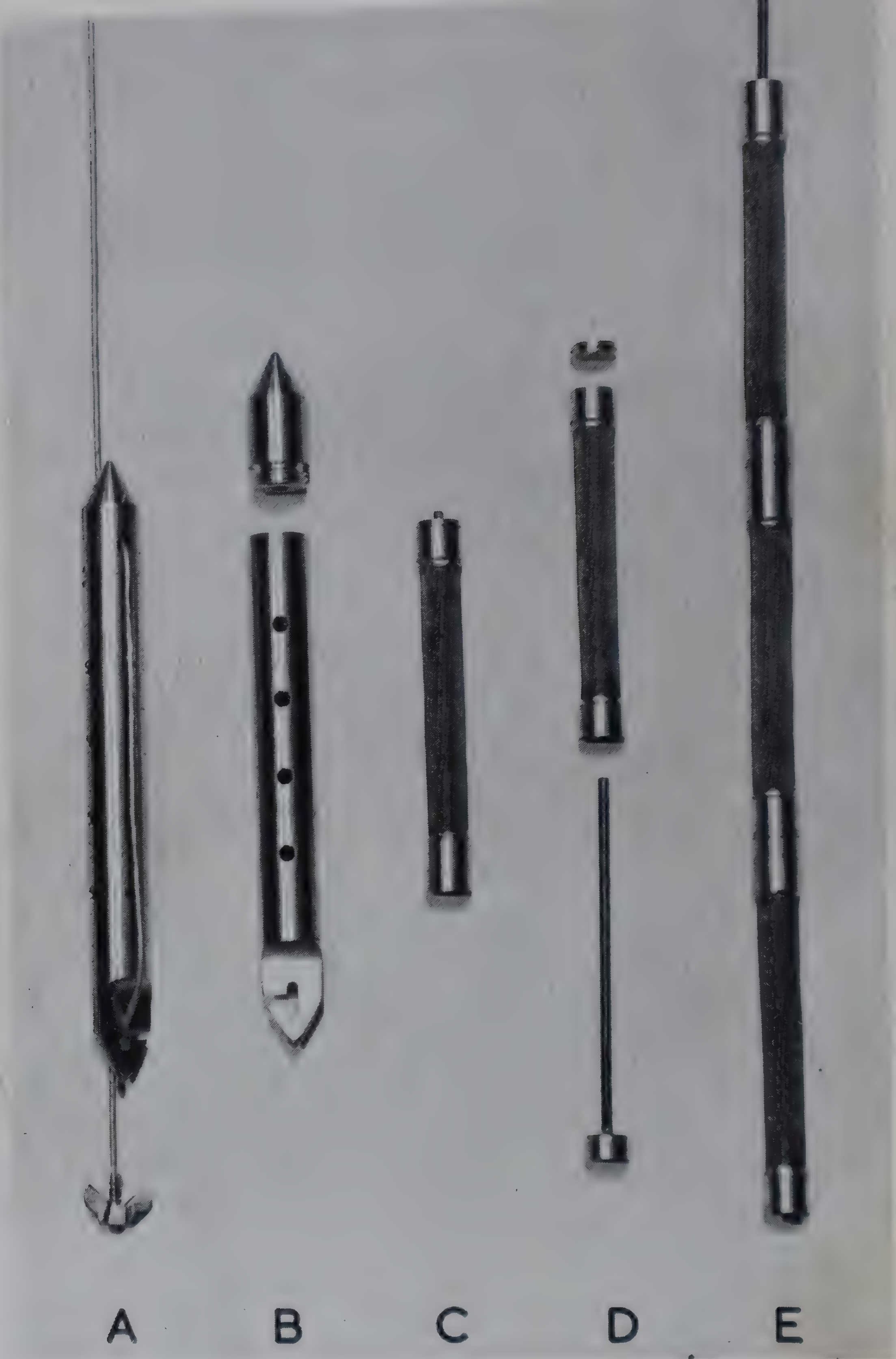
(b) Technique for obtaining comparative figures for the degree of infestation of experimentally-treated slaughter-house refuse, showing aeration of containers and method of trapping fully developed Blowflies (*see p.* 12)

PLATE 4

(a) Examples from a consignment of service shoes after storage abroad, showing damage by Woolly Bears (larvae of the Carpet Beetle, *Anthrenus vorax* (*see p.* 16)

(b) Testing for leaks during a commercial fumigation with methyl bromide under gas-proof sheets. The Halide leak detector lamp shows a green flame in the presence of dangerous concentrations of the fumigant (*see p.* 18)

PLATE 5

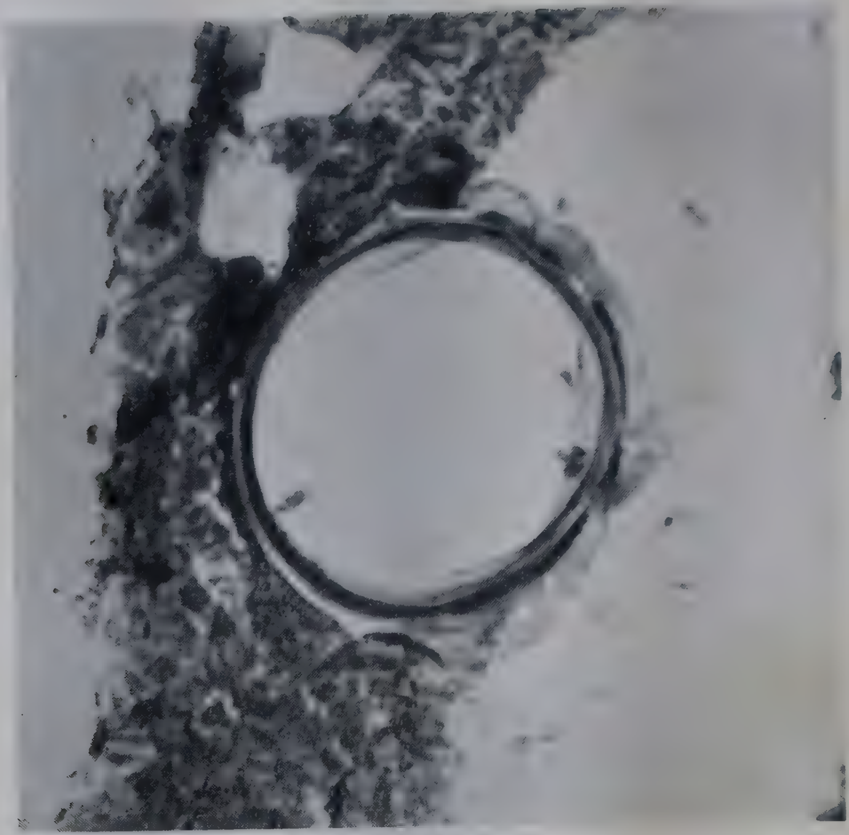


Insect containers for measuring the toxicity of fumigants to insects. C and D show the construction of the cages. For field use these are housed in strong containers (A, B) (*see p.* 20)

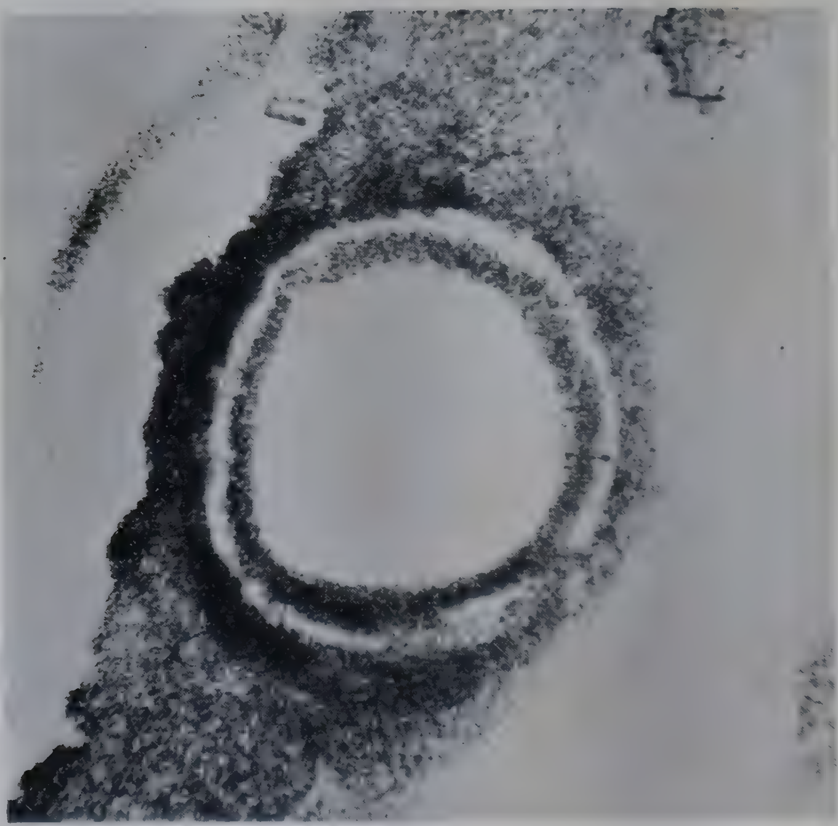
PLATE 6

Sectioning insect tissue with a freezing microtome. Air, chilled with liquid oxygen, passes downwards from the funnel over the microtome and prevents rapid thawing of the frozen tissue (*see p.* 28)

PLATE 7



(A)



(B)

Photograph (A) and autoradiograph (B) of a section showing one of the tracheal trunks of a Blowfly larva that has been killed with radioactive methyl iodide. The autoradiograph shows that the fumigant has passed through the tracheal wall into the surrounding tissue (*see p.* 28)

PLATE 8

Control of Blowflies in Slaughter-houses

In the previous Annual Report, mention was made of large numbers of flies which were obtained from treated experimental heaps of slaughter-house refuse and which had to be examined in some detail before any conclusions could be drawn about the efficacy of the treatments. Over 80,000 blowflies were eventually examined and it was found that all treatments had some repellent action against adult blowflies. Probably as a result of this, the larval infestation of the treated heaps was well below that of the untreated heaps, DDT treatments being the most effective. In addition to reducing the larval infestation, three treatments (DDT emulsion, DDT dust, and BHC dust) caused an appreciable kill of emerging adults. The order of emergence of blowflies breeding in natural competition in slaughter-house refuse was (1) *Phormia*, (2) *Lucilia*, (3) *Calliphora*. There appeared to be no tendency for one sex to emerge earlier than the other.

Towards the end of the fly season of 1948, 5 per cent DDT dust was applied to the refuse and the vegetation on waste ground adjoining a large slaughter-house, where the authorities co-operated whole-heartedly in the Laboratory's trial treatment and played their part by putting into effect recommendations for improved storage and clearance of the animal refuse. These measures prevented flies breeding on the premises; consequently, during the winter of 1948–9 few larvae could be found in the soil. A few *Calliphora erythrocephala* only were found which were known to have bred in a heap of soiled sacking too wet for burning.

During 1949, the slaughter-house authorities continued the systematic storage and collection of the refuse with the result that on only one occasion, linked with an unavoidable breakdown in the collecting system, were larvae found on the premises. Refuse and vegetation were regularly treated with 5 per cent DDT dust and, despite the long hot summer, the population of blowflies was held at a very low level.

In 1948, *Phormia azurea* was observed commonly resting on sunlit outside walls. In April, 1949, all walls near the refuse heap of the slaughter-house were sprayed with a DDT wettable powder, and the proportion of this species of blowfly quickly dropped from about 10 per cent of the total population to less than 1 per cent and remained at this level for the rest of the year.

Although blowflies on the slaughter-house premises were so successfully reduced in numbers during the 1949 season, a small population was always present and it is thought that this was maintained by continuous immigration from other breeding grounds in the neighbourhood.

Studies at the Laboratory on heaps of infested refuse have confirmed field observations that most mature blowfly larvae migrate at night in search of pupation sites. Even when the larval food was kept in constant darkness during the whole period of development and migration of the larvae, more than 90 per cent migrated between 6 p.m. and 9 a.m.

The only survey of slaughter-houses which it proved possible to make during the year was a visit to nine in the North of England, late in September, when the weather happened to be cold and wet. Species of flies collected on the tour were the same as those commonly found in the South and, in general, the problems met with were similar in both areas. (*A. A. Green*, *B. J. Southgate*, *Miss M. J. Kane*, *Miss D. G. Blackman*).

Changes in Resistance of Stocks of Houseflies

The resistance to pyrethrum of a stock of flies, obtained from a commercial laboratory, but subsequently bred by the Pest Infestation Laboratory method, has been compared with that of a group of P.I.L. flies bred in parallel. The comparison was made on flies of the first, third, fourth, fifth, sixth and seventh generations. The commercial strain was more resistant at the start but, in spite of some variability in the results, appeared definitely to be approaching the P.I.L. stock in its resistance; at the seventh generation the two strains were of equal resistance. An oversight in the rearing of the insects unfortunately led to loss of the commercial strain at this point, so it is not known what the subsequent trend of results would have been, and pressure of other work has prevented a repetition of the whole experiment.

Some attention has also been given to the quality of the solution of pyrethrins which is used as the standard for comparison, as there have been indications from time to time that the solution in individual bottles was abnormal. It is difficult to get conclusive evidence on this point. Since the conditions under which the standard insecticide is stored at the Laboratory might not have been satisfactory, tests have been made in which bottles of the standard pyrethrin solution, shown at the start to be equally toxic to houseflies, were stored in the dark at 0°, 20°, and 27°C. One of the lots of solution kept at 27°C. was divided into two, and each half-bottle poured into a beaker and back into the bottle twice weekly, to simulate intermittent use. After six months, all solutions were found to be still equally toxic. (*E. A. Parkin*, *A. A. Green*, *Miss M. J. Kane*, *Miss D. G. Blackman*).

Control of Household Insects

During the war, the Laboratory carried out a considerable amount of experimental work on the control of houseflies on behalf of the Services, but it has not yet proved possible to spare much time for experimental work on the control of other common household insects. Nevertheless, it has occasionally been possible to experiment with *ad hoc* methods of control under practical conditions when the Laboratory's advice on treatment has been sought. On several occasions, for example, the Laboratory was asked to help Local Sanitary Authorities, etc., to deal with infestations occurring under abnormal circumstances in which the routine methods of control could not be applied. Help was given on an experimental basis.

Most visits were paid to houses having infestations of carpet beetles, and it seems that damage by the larvae of the Varied Carpet Beetle, *Anthrenus verbasci*, is more widespread and more serious than had been supposed. Control has been effected in most instances by a combination of detailed inspection, careful cleaning of infested materials, cupboards, etc.. and the application of a DDT dust, but it is difficult to be sure that all insects have been eradicated. Furthermore, reinfestation can easily occur from free-flying beetles which are common out-of-doors during hot weather. A particularly important infestation occurred in bales of Army clothing returned to this country after storage in the Middle East. Many of the articles had been badly damaged by " woolly bear " (the larvae of *Anthrenus vorax*), and the infestation was continuing in this country in the warm, dry stores in which the clothing was kept. Detailed recommendations were made by the Laboratory for control of the existing

infestation and the treatment of newly received bales, but some time must elapse before the degree of success attained by these measures can be ascertained.

Several wasps' nests, difficult of access, were successfully treated by blowing benzine hexachloride smoke through a tube into the nest or by "injection" into the nest of a kerosene solution containing 0·2 per cent pyrethrins and 0·5 per cent DDT from the lance of a pneumatic sprayer.

Preliminary experiments on ants infesting houses indicated that control could often be achieved by poison baiting, but complete reliance could not be placed on the method. Much more work will have to be done to find out why the failures occur.

A heavy infestation of silverfish in a house was eradicated quickly and completely by dusting all floors with a 10 per cent DDT powder. (*A. A. Green*).

Evaluation of New Synthetic Materials as Insecticides

Collaboration with the Chemical Research Laboratory (D.S.I.R.) has continued on the evaluation as insecticides of high boiling residues, and their components, formed during the hydrogenation of certain tar products such as pyridine. The effect on Granary Weevils, *Calandra granaria*, has been determined of certain substances isolated from the distillation fractions obtained after hydrogenation and of a number of homologous or analogous compounds. Some of these pure compounds were more effective than the crude fractions, but none proved really toxic to the weevils when applied as solutions of 5 per cent or less in the normal warehouse spray oil, although concentrations of 10 per cent and 20 per cent showed considerable toxicity. The work is continuing as time and opportunity permit.

The co-operation with Dr. S. H. Harper of King's College, London, has also continued intermittently. The emphasis in this investigation has now swung to working on synthetic compounds closely allied to the pyrethrins and cinerins of natural pyrethrum. Fourteen compounds have been made by Dr. Harper and his colleagues and tested against houseflies in the Laboratory's small spray chamber. One of these compounds (the dl-trans chrysanthemic acid ester of dl-allyl-cyclopentenolone) corresponds to the "pyrethroid," the synthesis of which was announced early in the year by American workers, and was the best of the group, being almost as toxic as the Official Test Insecticide under the particular conditions of test; the conditions of test are known to influence strongly the ratios obtained in assays of the relative toxicity of insecticides. (*E. A. Parkin, A. A. Green, Miss B. Clayton, Miss M. J. Kane, Miss D. G. Blackman*).

Sprayer for Insecticides

During the war, the Laboratory designed a sprayer intended for the application of space sprays in rooms, halls, tents, etc., to control flying insects, such as flies and mosquitos. The sprayer, which can be operated by hand or connected to a supply of compressed air, was put through extensive tests to assess its efficiency at different stages of its development, and the final design was shown to produce a spray mist with characteristics better than those of the then existing sprayers of its type. The tests included determination of speed of knock-down and extent of eventual kill of flies and mosquitos released into a 1,000 cu. ft. chamber, a standard dose of a standard insecticide being atomized in each test. A paper has been published summarizing this work. (*A. A. Green*).

Variation in Insect Resistance

During 1949, numerous tests have been made with the selected test insect (the Confused Flour Beetle, *Tribolium confusum*) and fumigant (methyl formate) in the apparatus specially designed for the investigation into the variation in resistance of insects to insecticides. In estimating (*a*) the variability between individuals in a stock, and (*b*) the variability in response of a stock during the course of time, some of the experimental factors have been standardized throughout the tests, and others have been varied, in an effort to reduce to a minimum any heterogeneity in the results which could be ascribed to the experimental technique. The most important items standardized have been the use of a single stock line of beetles, with a standard technique for culturing and random selection of batches, and a fixed temperature (25°C.) and relative humidity (70 per cent). The most important of the variable factors have been those affecting dosage, namely, concentration of fumigant and period of exposure.

Experiments have been carried out with a series of concentrations for a fixed exposure period, and over a range of exposure periods at a fixed concentration. Experiments with concentration as the variable factor have, so far, given only heterogeneous results. Individual tests with period of exposure as the variable factor have given satisfactory homogeneous results, but repetition of tests has shown an unexpected lack of uniformity, which complicates the work. It is fortunate that it is easier to undertake tests in the apparatus using different periods of exposure: for an experiment involving a range of exposure periods at a fixed concentration can be completed in a day and therefore undertaken with batches of insects drawn at random from the same population; a test at different levels of concentration for a fixed time takes several days and the batches of insects cannot therefore be so uniform. The consistency of results obtained in different parts of the apparatus has been tested and found satisfactory. (*J. A. Hope*, *K. G. Gostick*).

FUMIGANTS

The work of the Section during 1949 has fallen chiefly under three headings:

I. The fumigation of large bulks of grain.
II. Study of the toxicity of fumigants to insects.
III. Reactions of fumigants with foodstuffs.

Fumigation of Large Bulks of Grain

The disinfestation of very large quantities of grain stored in bulk on floors has recently become a problem of increased importance. During the year the attention of the field team working on fumigants has been concentrated entirely on the study of the behaviour of methyl bromide and of certain chlorohydrocarbons when applied on or above the surface of such bulks. In the case of methyl bromide, some guide to its behaviour was given by the experience gained in earlier tests in barges and in silo bins. No further work has been carried out in silo bins during the year but a short article has been published pointing out the advantages of a circulating system.

APPLICATION OF METHYL BROMIDE ABOVE THE GRAIN SURFACE

In a number of instances where large bulks of grain have become generally infested, treatment with methyl bromide has been carried out by commercial fumigators acting on the instructions of the Infestation Control Division of the Ministry of Agriculture and Fisheries. This method of treatment was adopted since it was practical and permissible and seemed at the time to offer the best chance of effecting a useful measure of control. The Laboratory has carried out tests during three of these large-scale treatments. In addition, a series of smaller tests have been carried out in selected portions of a large bulk of maize stored on a floor. The depth of grain has been between 6 feet and 18 feet. In all these tests the distribution of methyl bromide was studied by measuring concentrations at numerous points in the bulk at various times throughout the period of treatment. Two types of spray-nozzle were used: one type produced a coarse spray which wetted the grain surface when the nozzle was held horizontally one or two feet above it; the other produced a finer mist which appeared to vaporize before falling on the grain surface.

The tests have provided information on the relative importance of the various processes which might be expected to affect the distribution of a highly volatile, heavier-than-air fumigant, such as methyl bromide, through a large bulk of grain.

(*a*) Downward penetration from a point of high concentration as a result of the relatively high density of the vapour. This is important when the methyl bromide is applied from coarse jets so that the grain in a small area in front of each jet is wetted. If a high concentration of vapour is distributed evenly above the grain surface, as by the use of fine nozzles, the downward penetration due to density differences appears to be negligible.

(*b*) Gaseous diffusion from the free space into the bulk and from points of high concentration within the bulk to neighbouring regions. This process is so slow that it appears to be of little significance in practice.

(*c*) Slow movements of air through the bulk due to the existence of temperature gradients or to other causes. These movements are undoubtedly largely responsible for the wide differences in distribution pattern observed in different parts of a large bulk. Unfortunately such effects are, in the main, uncontrollable.

(*d*) " Flow " of fumigant vapour according to the shape of the surface of the bulk of grain. These movements affect the distribution at the time of application in the air immediately above the grain and in the uppermost layer of the grain but usually have little effect on the distribution in the main bulk of grain unless air movements such as are described in (*c*) are taking place.

The general conclusion from these tests and from the biological observations made after the large-scale treatments is that at best this method of fumigation can give only a very limited measure of control. (*W. Burns Brown*, *H. K. Heseltine*, *G. A. Hamilton*).

APPLICATION OF CERTAIN CHLOROHYDROCARBONS TO THE GRAIN SURFACE

Ethylene dichloride (1, 2-dichloroethane) and carbon tetrachloride have been used singly and in admixture for the disinfestation of small bulks of grain

(as in farm bins) and for the treatment of " hot-spots " in larger bulks. These compounds are much less toxic to insects than methyl bromide so that much larger doses must be used. They are also much less volatile and are usually applied by coarse spraying of the grain surface from a " watering can " fitted with a rose or from a bucket pump and hose. Although these compounds and other mixtures in which they form the chief components have been in use in some countries for many years, little seemed to be known about their distribution in the grain after application to the surface. Information on this point was needed as a basis for recommendations on the treatment of small bulks of grain of different depths and at different temperatures. It might also lead to proposals for the general treatment of the much larger bulks which has proved such a difficult problem, though for this purpose the technical problems of applying very large bulks of fumigant would also have to be explored and overcome.

Preliminary tests have been carried out in which either ethylene dichloride or carbon tetrachloride has been sprayed evenly over the surface of small selected areas of a large bulk of wheat. Tests have been carried out on two depths of grain, 7 feet and 14 feet, using either of two rates of dosing, 4 and 8 gallons per 100 square feet of grain surface, and at surface temperatures between 2° and 35°C. The distribution has been determined by measuring concentrations, and it is clear that the two compounds tested behave very differently, the outstanding difference being the greater downward penetration of carbon tetrachloride. The surface-temperature has a very marked effect.

Further tests are planned using mixtures of these two compounds, and the series may be extended to other compounds and mixtures. (*W. Burns Brown, H. K. Heseltine, G. A. Hamilton*).

USE OF TEST INSECTS

The use of cages of test insects in field trials of the type described above in which concentrations are measured can provide information on the resistance of different species to the fumigant under test. Where laboratory data obtained under controlled conditions are also available, valuable evidence may be obtained on the extent to which such data can be applied under the variable conditions of field work. The use of test insects in this way is particularly necessary where mixtures of two or more fumigants are under test, because of the difficulty of providing toxicity data from laboratory tests. Plate 6 shows the cage-holders (A, B) which have been designed primarily for tests in bulks of grain. Each contains one of the cages (C) of the type used in the laboratory work on toxicity described in the next section. These cages are readily dismantled (D) for removal of insects and for cleaning, and in the laboratory tests several can be connected together for insertion into the fumigation chamber (E). A series of holders can be attached at intervals to a galvanized iron wire or cable which can be thrust down into a bulk of grain by means of a spear. Laboratory work has shown the importance of conditioning the insects and also of avoiding any unnatural disturbance shortly before exposure to the fumigant. If possible the cages are inserted into the grain on the day before the fumigation at points where gas concentrations will be measured. Temperature measurements are also taken at these points by means of thermocouples.

Toxicity of Fumigants to Insects

TESTS WITH METHYL BROMIDE

Studies have been continued on the resistance to methyl bromide of the various stages of the following species:—*Tribolium confusum*, *Calandra granaria*, *Laemophloeus minutus*, *Ptinus tectus*, and *Oryzaephilus surinamensis*. In addition some preliminary tests have been carried out on the larvae of *Trogoderma granarium*. The system of breeding each species outlined in the Annual Report for 1948 has been followed except that for certain tests insects have been bred at temperatures of 15°C. and 30°C. as well as at 25°C. The method of exposure to fumigant has also been substantially the same.

Tests with *T. confusum* and *C. granaria* have shown the importance of pre- and post-fumigation treatment on resistance, and have emphasized the need to condition samples to the fumigation conditions and maintain these conditions during the post-fumigation period. Differences due to different pre-fumigation treatments have so far been found to diminish as the exposure increases in severity so that they have little effect at the 100 per cent mortality level but are large at the 50 per cent level. Such effects may thus have little importance in fumigation practice, but failure to control them can result in considerable heterogeneity in the samples used in toxicity experiments.

Temperature has the greatest effect on resistance. In all the tests which have been carried out at 15°, 20°, 25° and 30°C. resistance increases as the temperature falls. Thus for adults of *C. granaria* exposed for a period of about 10 hours the concentration-time (c.t.) product expressed in mg. hr. per litre for complete kill is about 30 at 30°, 40 at 25°, 60 at 20° and 80 at 15°C. The exposure which gives complete control at 20°C. is of no practical value if given at 15°C., at which temperature only about 2 per cent of the insects will be killed. Hitherto toxicity experiments have been possible at 15° or 20°C. only in the colder months of the year, and for some time it has been the aim of the Laboratory to provide improved facilities for carrying out tests at lower temperatures. It is hoped to bring into use in 1950 two air-conditioned rooms maintained respectively at 15° and 10°C, the relative humidity in each case being controlled at 70 per cent. Each room will be equipped with apparatus which can be used for the measurement of insect resistance to fumigants.

Fumigation at low temperatures raises the question of whether insects reared at 25°C. are suitable for this purpose. Cultures of *C. granaria* have been reared at 15° and compared with cultures reared at 25° in tests carried out at 15° and 25°C. The insects were conditioned to the fumigation temperature for one week before treatment, earlier tests indicating no change after this period. The differences between the cultures were only slight.

Relative humidity appears to have much less effect than temperature upon resistance, and no differences have as yet been observed which would be of importance in fumigation practice. Again, however, these differences may introduce heterogeneity in the experimental results if humidity is not roughly controlled.

In tests with adults age appears to have little effect on resistance, but in the immature stages age is of great importance. A particular study was made of its effect with the larvae and pupae of *T. confusum*. Resistance increased gradually through the larval stage, dropping slightly before pupation. From this level the resistance of the pupae increased by 40 or 50 per cent to a maximum

at 2 to 4 days old and then decreased again to a value similar to that of adults. The resistance of the pupae to methyl bromide is inversely proportional to the rate of oxygen uptake. Such large changes in resistance in one stage are indicated by curvature of the exposure-mortality regression line when samples of mixed ages are tested. With the other test insects no such indication was given, though insufficient tests have been made on *O. surinamensis* pupae to show this. In this species such behaviour is in any case of little practical importance since the pupae are much less resistant than the adults.

A proper understanding of the relation between time and concentration for a given toxic effect is of great importance in the assessment of the effectiveness of trial fumigations in which concentration measurements have been obtained. A number of groups of experiments were carried out during the year to test this relationship. Unfortunately, an unusual heterogeneity appeared in the results of one or more experiments in each group, which has rendered the results as a whole unsuitable for the analysis of the time-concentration relationship which was planned. Investigation has shown that this heterogeneity in certain experiments probably resulted from the occasional presence of traces of phenol vapour in the air of the room in which the samples of insects were kept after fumigation. This experience has served to emphasize the care which must be given to controlling the conditions under which insects are kept after fumigation. (*Miss E. M. Reynolds, Miss B. D. Hole, I. McCalla, Miss M. F. East*).

Reactions of Fumigants with Foodstuffs

REACTION OF METHYL BROMIDE WITH PROTEINS

The investigation of the reactions of methyl bromide with amino acids in aqueous solution suggested that the most reactive group likely to be present in protein, other than the sulphydryl group, is the S-CH_3 group of methionine. In order to determine the relative importance of this group in the reaction between proteins and methyl bromide, tests have been carried out with casein and a globulin fraction of ground-nut protein. The globulin was isolated by extracting fat-free ground-nut meal with 10 per cent sodium chloride solution and purified by repeated dialysis. The globulin contained 0·9 per cent and the casein 3·3 per cent methionine, as determined by the method of Baernstein (*J. biol. Chem.*, 1934, **106**, 451) and the colorimetric method of McCarthy & Sullivan (ibid., 1951, **141**, 871).

Methionine reacts with methyl bromide to form a sulphonium bromide. In order to determine the extent of this reaction in protein it was necessary to select at least one method of analysis which would differentiate between methionine and the sulphonium bromide. The colorimetric method of McCarthy and Sullivan, when applied to the hydrochloric acid hydrolysate, was found to be specific for methionine in the presence of as much as ten times the weight of sulphonium bromide. The number of methyl groups attached to oxygen and sulphur was determined by the Baernstein method, which thus gave a measure of the methionine content of the untreated protein and also of the increase in these groups after exposure to methyl bromide.

Casein and ground-nut globulin were exposed to methyl bromide vapour in glass flasks for six days at 25°C. At the end of each exposure the methyl bromide which had not reacted was removed by aeration. The amount of

methyl bromide which had reacted was calculated by determining the increase of non-volatile bromide in small ashed samples of each protein. The methods mentioned above were then used in an attempt to locate the corresponding number of methyl groups.

In the ground-nut globulin about 60 per cent of the methyl groups were found to be attached to oxygen or sulphur. The reduction in methionine content, however, accounted for only about a quarter of these, indicating that a considerable proportion were present as $O\text{-}CH_3$ groups. Further evidence of a reaction with an OH group and the carboxyl group in particular was obtained when methyl alcohol was detected in the fractional distillate from a suspension of the globulin in dilute alkali. It has not been possible to obtain a quantitative estimate of the methyl alcohol produced, as the recovery of added methyl alcohol from an alkaline suspension of globulin was only about 30 per cent. It seems probable, however, that some esterification of carboxyl groups does occur. Similar analysis of the treated casein showed that 70 per cent of the methyl groups were attached to oxygen and sulphur, but in this case a much greater reduction in methionine content was detected, indicating that the reaction with methionine is responsible for a larger part of the reaction with this protein. Methyl alcohol was still detectable, however, in the distillate from an alkaline suspension.

In both these proteins, however 30 to 40 per cent of the methyl groups known to be present are still not accounted for. It seems likely that some reaction occurs with one or more of the nitrogen groups but no satisfactory method has so far been found to detect the small changes in the nitrogen likely to be involved. (*S. E. Lewis*, *Miss B. G. Halls*, *Miss E. M. Greet*).

ISOTOPE TRACERS

Because of the nature of the work the Section has functioned largely as a single research team, every member being associated at some time or another with all aspects of the experimental work. Principal lines of work are however indicated as follows:—

F. P. W. Winteringham—Isotope chemistry, general integration of the work of the Section.
A. Harrison —Syntheses. Radiometric assays.
R. G. Bridges —Potentiometry, diffusion, chromatography.
Miss P. M. Loveday—Histochemistry, biological items.
G. C. Hellyer —Miscellaneous.

The work of the Section has developed along three lines:—

I. Studies on the fate of insecticides in food products.
II. Studies on the fate of insecticides in insects.
III. Studies in isotope and physical chemistry fundamental to (I) and (II).

Fate of Insecticides in Stored Products

The emphasis in these studies has been, and will be, on those problems which can be attacked only with considerable difficulty, if at all, by conventional analytical methods. For example, the studies made with a radioactive analogue of DDT were conducted at low concentrations related to those obtaining in the field and it was possible to trace the insecticide and its metabolic products

as far as their excretion by animals eating DDT-contaminated food, i.e., as far as the insecticide could possibly have any physiological significance.

METHYL BROMIDE RESIDUES IN TOBACCO

The determination of bromide residues in tobacco fumigated with methyl bromide is difficult because tobacco may naturally contain bromide up to the order of 100 p.p.m. and chloride up to the order of 20,000 p.p.m. Residual bromide due to fumigation may be even less than the natural bromide alone. Despite the high Cl^-/Br^- ratio, however, it was found just practicable to determine the total bromide by direct potentiometric titration of prepared extracts. The accuracy of the method when applied to fumigant residues in tobacco was tested as follows:—Tobacco leaf (12 per cent moisture) was exposed to Br^{82} labelled methyl bromide at an average concentration of 15 mg. per litre for 1, 2, 5, and 7 days at room temperature. The unabsorbed methyl bromide was aired off. Samples were then ashed, extracted, and the residual bromide determined potentiometrically, allowance being made for the natural bromide determined in control samples. Radio-bromide, which could have derived from the radioactive fumigant alone, was assayed radiometrically in second aliquots. The results are summarized below and indicate the accuracy of the potentiometric method:—

Fumigation period	— days	1	2	5	7
Residue calculated from sorption data	—p.p.m.	137	313	621	—
Residue determined potentiometrically	—p.p.m.	89	225	610	918
Residue assayed radiometrically	—p.p.m.	87	218	608	930

The labelled fumigant was prepared from pile irradiated potassium bromide by the following steps; an asterisk denotes labelled material:—

$$\text{K Br*} \longrightarrow \text{AgBr*} \xrightarrow[\text{at } 750^\circ]{\text{Reduction}} \text{H Br*} \xrightarrow[\text{at } 120^\circ]{\text{Methylation}} \text{CH Br*}$$

SORPTION OF METHYL BROMIDE BY TOBACCO, GROUND-NUTS, ETC

By attaching a screened Geiger-Müller counter to a two-chamber sorption apparatus it has been possible to measure continuously the total sorption of a radioactive fumigant by a single sample of absorbent material. The apparatus has been used for measuring the sorption of methyl bromide by tobacco, and by ground-nuts:—

	Average free-space concentration of methyl bromide (mg. per litre)	Total sorption as p.p.m. methyl bromide 1 day	2 days	4 days
Tobacco				
	1 mg./l at 25°C.	60	78	89
	15 ,, ,, 25°C.	250	470	870
	15 ,, ,, 20°C.	145	275	530
	25 ,, ,, 20°C.	240	440	820
Ground-nuts				
	7·5 mg./l at 20°C.	185	230	282

It will be seen that in the case of tobacco the ratio (concentration of sorbed fumigant)/(concentration of free fumigant) is considerably higher at 1 mg. per litre than at 15 mg. per litre, which suggests that if tobacco were fumigated in a close chamber at very low concentrations, e.g. ,0·1 mg. per litre, a serious proportion of methyl bromide would be lost by sorption.

PENETRATION OF METHYL BROMIDE INTO GROUND-NUTS AND INTO WHEAT GRAINS

Samples were exposed to radioactive methyl bromide for 24 hours at room temperature. Microtome sections of the exposed wheat grains, and of single ground-nuts were then clamped against photographic plates. The autoradiographs obtained indicated that in the case of the ground-nuts penetration was complete and the bromide (resulting from the protein-methyl bromide interaction) was evenly distributed throughout the tissue. In the case of the whole wheat there was limited penetration beyond the aleurone layer, the distribution roughly corresponding to the known sulphur distribution in wheat grains. Radiometric analysis of the ground-nut sections showed: (*a*) 99·8 per cent of the non-volatile bromide was easily water-soluble; (*b*) loss of unreacted methyl bromide was very rapid from the sectioned tissue and about 75 per cent of the total methyl bromide dissolved in the oil obtained by compressing the cooled nuts was volatile, the remaining 25 per cent probably being associated with solid matter suspended in the oil.

CHEMICAL INTERACTION BETWEEN METHYL BROMIDE AND AMINO ACIDS ISOLATED FROM WHEAT

As part of studies being made to account completely for the chemical fate of methyl bromide in fumigated wheat by using methyl bromide labelled with radioactive carbon (C^{14}) and radioactive bromine (Br^{82}), some experiments have been made on the isolation of amino acids from wheat and on their reactivity towards methyl bromide. It is known from the researches made on wool protein and on the action of war gases on proteins that methyl bromide will methylate the NH^2– and SH– groups of certain proteins, and, under certain conditions, will react with methionine forming sulphonium bromides. In the case of wool protein the formation of the volatile dimethyl sulphide with methyl bromide has also been demonstrated. These data have provided a useful basis for the methyl bromide researches.

Wheat protein was subjected to acid hydrolysis. The resulting amino acids were separated by unidimensional paper chromatography. The separated acids were exposed to radioactive methyl bromide. Any reaction was indicated by the formation of non-volatile bromide which could be assayed radiometrically. The weight of radio-bromine fixed by unit area of the chromatographed amino acid was taken as a measure of the reactivity. With the possible exception of aspartic acid all the amino acids reacted with methyl bromide. It was found that tryptophane, valine, leucine, and the sulphur-containing amino acids, cystine and methionine, are the most reactive under these conditions.

Isotope exchange experiments of the type shown below were made:—

$$CH_3\,Br + \underset{\substack{\text{(By treating the}\\\text{protein with}\\\text{radioactive}\\\text{methyl bromide)}}}{Br^{-*} - \text{Protein}} \rightleftharpoons CH_3\,Br^{*} + Br^{-} - \text{Protein}$$

The exchange in this system was always far more rapid than when the bromide was deposited as a salt from aqueous or alcoholic solvents or by exposing the protein to bromine or hydrobromic acid. Temporary increase of the moisture content of the protein greatly reduced the rapidity of the exchange when the bromide was deposited by exposure to methyl bromide.

This would be explained if the inorganic bromide resulting in protein by exposure to methyl bromide were located at active sites responsible for the primary physical adsorption process. While the bromide is concentrated at these sites it would be able to exchange with the bromine of methyl bromide vapour subsequently applied, a temporary increase in moisture allowing the bromide to diffuse away from these sites and so reducing the exchange facility as observed.

Alternatively the experimental results would be explained if in fact, despite aeration, some methyl bromide were firmly held by the protein in potentially molecular form, e.g., an unstable salt of the sulphonium type. If this compound were readily hydrolysed in the presence of water, then the apparent loss of exchange would also be accounted for. The use of C^{14}-labelled methyl bromide should provide the solution to this problem.

Preliminary experiments with partly deaminated protein indicated that removal of the NH^{2-}groups is associated with a reduction in the reactivity of the protein with methyl bromide. This result is tentative in so far as it is not yet certain to what extent the protein was physically modified by the deamination process.

FATE OF DDT SPRAYED ON TO GRAIN

These studies were made with the collaboration of the Cereals Research Station, the Veterinary Research Laboratory, and the British Baking Industries Research Laboratory.

The bromine analogue 2, 2 Bis- (*p*-bromophenyl) 1, 1, 1- trichloroethane, " D (Br) DT," was used instead of ordinary DDT. This analogue closely resembles normal DDT in its chemical, physical and biological properties and possesses the great advantage that it can be labelled in a highly stable position with radioactive bromine, (Br^{82}), an isotope which is very suitable for this type of experiment.

Radioactive bromine of high specific activity was prepared from a bromobenzene-aniline mixture by the Szilard-Chalmers reaction at a high neutron flux. The labelled insecticide was prepared in the following steps:—

$$AgBr^* \xrightarrow[\text{(oxidation)}]{} Br_2^* \xrightarrow[\text{(Catalytic bromination)}]{} C_6H_5Br^* \xrightarrow[\text{(Condensation, etc.)}]{} D(Br^*)DT.$$

50 ml. of a 0·36 per cent solution in " odourless distillate " of the labelled insecticide was sprayed on to 3 kg of wheat grain spread uniformly in a thin layer. Part of the grain was then milled, baked into bread and the bread fed to rats. The unmilled grain was fed directly to hens. The concentration of D (Br*) DT was determined radiometrically in all the products of the milling process and finally in representative samples of the tissues, excreta, etc., of the sacrificed animals. The results are summarized below and in all cases are expressed as D (Br*) DT p.p.m. wet weight.

Milling experiments

Sample	*D(Br*)DT. p.p.m.*	*Percentage total D(Br*) DT in original grain*
Unmilled grain	40·2	100·0
Dust direct from scourer	458	1·4
Dust from scourer expansion chamber	582	1·8
Water used for washing and whizzing	1·03	4·1
Coarse offal	127	24·0
Fine offal	134	21·0
Flour (85% extraction)	14·6	29·3
		81·6

5·12 per cent by weight of the original grain was lost on milling, which no doubt accounted for the remaining 18·4 per cent of the D(Br*) DT present in the original grain.

Baking experiments

Samples of the flour were made into bread under standard conditions:—

Sample	*D(Br*)DT. p.p.m. found*
Dough	9·7
Bread crumb	10·3
Bread crust	15·6

Animal feeding experiments

Samples of the bread and unmilled grain were fed to rats and to hens respectively for about one week as an exclusive diet except for water which was given *ad libitum*. The animals were then sacrificed and dissected. The results of radiometric analysis are given below.

Sample	*D(Br*)DT. p.p.m. (Mean values) wet weight*
Hens—heart tissue	0·94
gizzard (including fat)	1·11
brain	0·13
spleen	0·55
sciatic nerve	0·25
ovaries	1·21
kidney	> 0·25
liver	1·67
total excreta (incl. urine)	3·10
Rats—brain	0·94
liver	2·60
faeces	23·1
urine	124·3 μg (volume of urine and therefore concentration, not known).

Of the animal tissues the highest concentrations occurred in the liver of all

the animals. The high concentrations found in the total excreta of the hens, and in the faeces of the rats is interesting. The wide distribution of insecticide in all the tissues assayed suggests that a significant fraction of it would be retained for considerable periods after administration.

Of the total activity excreted by the hens, about 5 per cent appeared to be water-soluble and could not be removed from the aqueous phase by benzene. This activity was probably due to the water-soluble metabolite Di- (*p*-bromophenyl) acetic acid, to which the corresponding DDT derivative has been demonstrated in the urine of rabbits fed with olive oil containing 50,000 p.p.m. of DDT (White and Sweeney).

Of the total activity excreted in the faeces of the rats, 23·5 per cent behaved as the water-soluble metabolite, but this might have been due to contamination by the urine of which 94·3 per cent of the total activity behaved as the water-soluble metabolite.

In order to determine whether a corresponding detoxification occurred in man, one of the team consumed 30g. of a specially prepared bread sample containing approximately 200 p.p.m. D(Br*)DT of very low specific activity. The total urine (1·2 litres) passed over the succeeding 48 hours, was collected and analysed. Quantitatively the results indicated that 5 per cent of the total D (Br*) DT administered was excreted in the urine in the first 48 hours succeeding ingestion. 35·6 per cent of the activity excreted was due to D (Br*) DA, while the remaining 64·4 per cent behaved as unchanged D (Br) DT.

Fate of Insecticides in Insects

The great sensitivity and specificity of the isotope tracer technique has made it possible to study the fate of insecticides in individual insects.

AUTORADIOGRAPHIC LOCATION OF HALIDES IN INSECTS POISONED BY EXPOSURE TO RADIOACTIVE METHYL HALIDES

The technical problem in these studies was to prepare autoradiographs without interfering with the distribution of the water-soluble halides liberated in the tissue during poisoning. Low resolution autoradiographs of the bromide in sections of poisoned larvae of *Calliphora erythrocephela* were obtained as follows. Fully grown larvae were exposed for 18 hours to Br^{82}—labelled methyl bromide at a concentration of 400 mg. per litre at room temperature. The larvae were fixed by cooling to—180°C. followed by dehydration at—25°C. at a pressure of 10^{-4}mm. of mercury (Altmann—Gersh technique). They were then embedded in vacuo and sectioned in the usual way. Dry, dewaxed sections, mounted on microscope slides, were clamped to photographic plates and exposed for 5 days. The final autoradiographs indicated high bromide concentrations in the integument and round the walls of the lateral tracheae but the short half-life of the bromine isotope made proper development of the technique difficult.

There is reason to believe that the toxic action of methyl iodide is very similar to that of methyl bromide. Further studies were therefore made with methyl iodide labelled with I^{131}, the longer half-life of this isotope (8 days) allowing greater time to be spent on the preparation of the autoradiograph. Larvae were killed by exposure to labelled methyl iodide at a concentration of approximately 5 mg. per litre for 18 hours. They were fixed, dehydrated and sectioned

before. A 15-mm. square of high resolution stripping emulsion was then pplied to each section by pressing on with a moist filter paper. In this way was possible to ensure the required intimate contact between section and nulsion without having to submerge the section in water as in the original elc technique which would have leached out the radioactive iodide that was eing located. The following information was obtained by examining auto-idiographs of transverse and longitudinal sections:—

There was a wide distribution of active iodide throughout the tissue. This night result from a diffusion of iodide through the body fluids before and after eath or by rapid penetration and diffusion of methyl iodide before decomposi-ion. High concentrations of iodide were found in the epi- and exocuticular ayers of the integument and in the underlying hypodermal cells, also in the xo- and epicuticular layers of the main tracheal trunks (though absent from he tracheal endo-cuticle), and in the epithelial matrix of the tracheae. This uggests that entry, in the blowfly larva, is through the tracheae and the body urface generally. There was also a high concentration of iodide in the salivary glands.

ADIOMETRIC ANALYSIS OF ISOLATED TISSUES

alliphora larvae exposed to lethal concentrations of labelled methyl iodide we.e dissected under cooled xylol (to prevent diffusion of water-soluble iodide). Isolated organs and samples of body tissues were dried, weighed and assayed under a thin window Geiger-Müller counter.

Results so far obtained showed a uniform distribution resulting probably from diffusion, suggesting too great a time lapse between exposure to the fumigant and dissection.

TRACER-HISTOCHEMICAL STUDIES

As part of the programme on the bio-chemical action of insecticides *in vivo* an experimental survey was made of the action of a range of fumigants on the glutathione in *Calliphora* larvae. Live animals were exposed for 45 minutes to saturation or near-saturation concentrations of several fumigant vapours in small glass-stoppered flasks. The larvae were then dissected in saturated ammonium sulphate and thiol groups located by a modified nitro-prusside test (Fink). Under these conditions reduced glutathione was the main tissue constituent responsible for a thiol reaction. Control larvae were dissected and examined under the same conditions. The results are compared below:—

++ indicates complete destruction of reactive thiol groups.
+ ,, partial ,, ,, ,, ,, ,,
− ,, no detectable effect.
−− ,, slight activation.

Substance		*Reaction*
Methyl chloride	CH_3Cl	+
Methyl bromide	CH_3Br	++
Methyl iodide	CH_3I	+
Carbon tetrachloride	CCl^4	−
Chloroform	$CH\ Cl_3$	−
Trichlorethylene	$C_2H\ Cl_3$	−
Ethylene dichloride	$C_2H_4Cl_2$	−
Ethylene dibromide	$C_2H_4Br_2$	−

Substance		*Reaction*
Trichloracetonitrile	CCl_3CN	+ +
Chloropicrin	CCl_3NO_2	+ +
Ammonia	NH_3	+
Hydrogen cyanide	HCN	– –
Methyl formate	$H.COO\ CH_3$	– –
Formaldehyde	H.CHO	–
Carbon disulphide	CS_2	+
Ethylene oxide	$(CH_2)_2O$	+ +
Mercury	Hg	– (Exposure—48 hr.)

All the compounds of the first group are alkylating agents and would be expected to methylate thiol groups. The halogen-hydrocarbons of the second group are relatively inert chemically, their biological action being mainly narcotic. The absence of any effect on the glutathione is therefore not surprising. The first two compounds of the third group are well known lachrymators. It is well established that their action is to inhibit enzymes whose functions depend upon the integrity of SH groups in the protein moiety. The action of ammonia is not understood. Compounds of the third group are reducing agents and apparent activation of the glutathione reaction was no doubt due to reduction of –S–S– groups. It is not clear why carbon disulphide should suppress the glutathione reaction. Reaction with ethylene oxide is probably due to the formation of the monothio ethylene glycol derivative, thus:—

The failure to detect any action by the mercury was surprising. It is widely believed that the toxic action of mercury and organic mercurials is due to the inhibition of SH enzymes (e.g. succinoxidase) by the formation of mercaptides:—

$$R.SH + Hg\ (Cl\text{—}Benzoate) \longrightarrow R.S.\ Hg.\ benzoate + HCl$$

The fact that enzymes so inhibited can be reactivated by dithiols, reduced glutathione, etc., lends considerable support for this view. The negative results might have been due to insufficient exposure time, although the larvae displayed definite symptoms of poisoning. On the other hand Haarmann believes that inorganic mercury is not specific for—SH groups but first combines with the peptide linkage of the protein and then with the nitrogen of imidazole groups.

One interesting feature of these experiments was the remarkable rapidity with which the poisons entered the larvae. Although only 45 minutes was allowed for each exposure the glutathione reaction (in positive tests) was inhibited in widely different tissues, e.g., muscle tissue, salivary glands.

Miscellaneous Studies in Isotope and Physical Chemistry

Although of no direct bearing on insecticide problems the work under this heading unavoidably absorbs a considerable fraction of the total effort. Progress made under this heading during the past year will be indicated briefly.

ASSAY OF RADIOACTIVE ISOTOPES

A laboratory technique has been developed for mounting, in a geometrically uniform manner, silver halide precipitates on alkathene-backed lead discs for the quantitative assay of the isotopes, Cl^{36}, Br^{82}, I^{131}. The technique is in regular use for the assay of these isotopes.

An internal flow-type counter has been designed and constructed for the assay of weak β-emitters such as C^{14} and S^{35}. The sample for assay, e.g., $BaCO_3$, is mounted in a precisely reproducible manner within the sensitive volume of a counter through which flows a constant mixture of helium and alcohol vapour at constant temperature and pressure. In this way a much larger fraction of the β-particles may be detected. The counters constructed were three times more efficient for C^{14} than the most sensitive commercial end-window counter available.

For the quantitative radiometric assay of C^{14} it is necessary to concentrate the total carbon in a form such as $BaCO_3$ suitable for the flow-type counters in use at this Laboratory. Techniques have been developed for the recovery of carbon from solid, liquid or gaseous compounds.

A high vacuum manifold, reservoirs, Töpler pump, internal gas-counter, etc., have been assembled for the recovery and assay of tritium (radioactive hydrogen) which is to be used as an auxiliary tracer for C^{14}.

PRODUCTION OF RADIOACTIVE BROMINE OF HIGH SPECIFIC ACTIVITY

In order to obtain radioactive bromine of specific activity sufficiently high to permit measurements to be made over a period of several weeks the Szilard-Chalmers method is employed. The method usually involves the irradiation of an organic bromine compound so that the recoil-freed halogen can be extracted in a "carrier-free" condition. The thermal conditions and intense γ-radiation associated with the high neutron fluxes of the Harwell Pile introduce complications, and some *ad hoc* experiments have been made to determine the optimum conditions of irradiation.

ISOTOPE EXCHANGE REACTIONS

In order to label a compound in a reliable manner it is important that the isotope will not exchange isotopically with the natural atoms of a different compound. In all tracer studies, therefore, this possibility must be investigated. It was shown that the radioactive bromine of labelled bromobenzene or the bromine analogue of DDT would not exchange significantly with bromides under various conditions. The Br^{82} or I^{131} of labelled methyl halides would exchange slowly with halides in aqueous solution and more rapidly in aqueous acetone. This property has been turned to advantage in the preparation of labelled methyl iodide on the micro-mole scale.

INCORPORATION OF S^{35} INTO GROWING WHEAT

Experiments have been set up to incorporate radioactive sulphur into mature wheat grains. The wheat is being grown in sand culture, the nutrient solution containing S^{35}—labelled magnesium sulphate. The wheat will be used for studying the sulphur distribution by tracer-chromatography technique and for studying the interaction between the sulphur-containing amino acids and residual insecticide on storage.

DIFFUSION OF METHYL BROMIDE INTO COLUMNS OF GRAIN, FLOUR, ETC.

Data have been collected on the penetration of methyl bromide into 100-cm closed columns of products such as glass beads, wheat grains and flour. Th source of methyl bromide is in equilibrium with a solution of methyl bromid in dibutyl phthalate which thus behaves as a large constant concentratio reservoir. As the vapour diffuses along the column small samples are draw and the concentration gradients determined. There appeared to be no signifi cant effect due to slight air-movement at the surface of the column at the source Some results are tabulated below.

Free space concentrations of methyl bromide expressed as percentages o the maximum possible equilibrium concentration (about 400 mg. per litre).

Column	*Distance from surface at reservoir* *cm.*	*Time after commencement of diffusion—hours* 24	48	168
1,890g. glass beads	5	98·8	100·0	100·0
	45	83·0	91·1	94·3
	85	60·8	84·6	86·0
890g. wheat	5	97·9	100·0	100·0
	45	39·8	45·8	64·9
	85	14·1	23·2	45·7
644g. wholemeal flour	5	99·1	100·0	100·0
	45	31·4	42·6	66·1
	85	6·6	15·4	47·1

The parallel nature of the concentration gradients in the grain and flou columns was surprising because it was expected that the much greater sorptior known to occur with flour, would have considerably impeded penetratior More detailed comment must await further experimental and theoretical treat ment.

EFFECT OF INTENSE β AND γ-RADIATION ON INSECTS

It is possible to produce intensive sources of penetrating γ-radiation b irradiating suitable elements (e.g., cobalt) in the atomic pile. Intense γ-radiatio will damage or even kill living tissue. To investigate the theoretical possibilit of insect population control by this means the following experiments wer made. About 20 *Calandra granaria* adults were irradiated at a distance of 1 cr for 2 hours and for 4 days respectively by a 15-millicurie source of radiu (a platinum sheath filtered off all α-particles). Each group of insects was the removed, placed on fresh food, etc., and observed alongside controls for sever weeks. No effects were detected as a result of the 2-hour irradiation. Of tho irradiated for 4 days, 3 still survived after 3 months, 15 died before any of th control insects died naturally. Two insects were lost. None of the survivi insects laid viable eggs. Although very tentative, the experiment suggests th effective control would involve enormous and dangerous levels of radioactivit It is of interest to note that at a distance of 1 metre a 15-mc. source of radiu produces the maximum permissible radiation level for man.

APPENDIX I

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2. BUTTERFIELD, D. E., PARKIN, E. A. and GALE, M. M. (Miss). The Transfer of DDT to Foodstuffs from Impregnated Sacking. *J. Soc. chem. Ind., Lond.*, 1949, **68,** 310–313.
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4. HOWE, R. W. Studies on Beetles of the Family Ptinidae. I. Notes on the Biology of Species in Britain. *Ent. mon. Mag.*, 1949, **85,** (1021), 137–139.
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6. PARKIN, E. A. Pyrethrum-in-oil Sprays for Household and Warehouse Use. *Pyrethrum Post*, 1949, **1** (3), 16–18.
7. PARKIN, E. A. The Control of Insects Infesting Stored Foodstuffs, I and II. *World Crops*, 1949, **1** (3), 103–106 and **1** (4), 155–159.
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9. SOLOMON, M. E. The Natural Control of Animal Populations. *J. anim. Ecol.*, 1949, **18** (1), 1–35.
10. WINTERINGHAM, F. P. W. Preparation of Silver Bromide Precipitates for Radioactivity Measurements. *Nature*, Lond., 1949, **164** (4161), 183–184.

APPENDIX II

Staff of the Pest Infestation Laboratory
1949

Director of Pest Infestation Research—G. V. B. Herford, O.B.E., M.Sc.

Principal Scientific Officers—E. A. Parkin, Ph.D., M.Sc., D.I.C.; T. A. Oxley, B.Sc., A.R.C.S.; W. B. Brown, M.Sc., F.R.I.C., A.R.C.S., D.I.C.

Senior Scientific Officers—M. E. Solomon, M.Sc.; F. P. W. Winteringham, A.R.I.C.; P. S. Hewlett, B.Sc.; †R. W. Howe, B.Sc.

Scientific Officers—Miss H. B. Galleymore, M.Sc.; J. A. Hope, B.Sc.; S. E. Lewis; Mrs. P. J. Maycock, B.Sc.; Miss S. G. Rawle, B.Sc.

Senior Experimental Officer—A. A. Green.

Experimental Officers—A. M. Cunnington; A. Harrison; H. K. Heseltine, B.Sc.; Miss M. B. Hyde, M.Sc.; Miss H. C. N. Turnbull, M.A.

Assistant Experimental Officers—R. G. Bridges; H. D. Burges; *Miss M. Clendon, B.Sc.; W. T. Dundas, B.Sc.; Miss W. M. Eustace; *Miss M. Gale, B.Sc.; G. A. Hamilton; Miss B. G. Halls; J. P. Heslop; Miss B. D. Hole; *Miss E. E. Holland, B.Sc.; Miss J. R. Long; Miss P. M. Loveday, B.Sc.; I. McCalla; *T. Rhynehart; Miss G. M. Skellon, B.Sc.; *Miss M. Stephenson, B.Sc.; Mrs. E. M. D. Smith; Miss M. K. Winckler; G. E. Woodroffe.

Senior Assistant (Scientific)—A. E. Broughton.

Assistants (Scientific)—Miss B. E. Adamson; Miss D. G. Blackman; *Miss F. J. Bowyer; D. Budd; *W. A. Carter; Miss B. Clayton; Miss J. E. Currie; Miss M. F. East; K. G. Gostick; Miss E. M. Greet; Mrs. U. E. Harding; G. C. Hellyer; *Mrs. B. Hull; Miss M. J. Kane; Miss J. M. Mitchell; Miss E. A. Myerscough; Miss E. M. Reynolds; *Miss W. J. Root; B. J. Southgate; K. I. Street; J. Waller; Miss S. R. Wiley.

Senior Photographer—J. H. Hammond.

Assistant Photographer—Miss A. M. Stott.

Clerks and Typists—H. W. Cooke; Mrs. M. N. Dales; *Miss A. M. Evans; Mrs. P. Horwood; Miss R. How; *Mrs. J. Lammin; Miss L. E. Ranscombe; Miss M. M. Wood.

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Instrument Maker—W. Cordaroy.

Fitter—C. Gray.

Carpenter—J. Gray.

Cleaners—Mrs. M. Williams; Mrs. A. Clements; Mrs. Waters.

Gardeners—A. Jackson; A. O. Moss.

† Serving in Nigeria
* Resigned in 1949

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

REPORT OF THE PEST INFESTATION RESEARCH BOARD

WITH THE REPORT OF THE
DIRECTOR OF PEST INFESTATION RESEARCH

FOR THE YEAR 1950

LONDON: HER MAJESTY'S STATIONERY OFFICE
1952

REPORT OF THE PEST INFESTATION RESEARCH BOARD FOR THE YEAR 1950

) the Lords of the Committee of the Privy Council for ;ientific and Industrial Research

Y IT PLEASE YOUR LORDSHIPS,

E, The Pest Infestation Research Board, beg leave to present a report on our oceedings during the year 1950.

RESEARCH PROGRAMME

The year has been marked by steady progress in all branches of the work of e Laboratory. Bearing in mind present limitations of staff and accommoda-on, we consider that a reasonable balance has now been struck in the pro-amme of research between the practical work necessary for the solution of y to day problems and longer range basic research. We look forward, how-er, to the work of the Laboratory as a whole being strengthened by an increase the number of research staff as soon as circumstances permit.

Following is a summary of developments on the more outstanding items in e current programme of research. They are more fully described in the Report the Director of Pest Infestation Research, which is appended.

CURRENCE, DISTRIBUTION AND ACTIVITY OF INSECT PESTS

There has been a considerable increase in the field work undertaken by the ology Section of the Laboratory, and although it is too early to report definite sults, we welcome this step as ensuring that the biological work is being main-ined on a proper basis of field ecology.

1. Through the co-operation of the Infestation Control Division of the inistry of Agriculture and Fisheries, a large "mixed" warehouse has been ade available to the Laboratory for observational work on insect populations der normal storage conditions. Quite apart from any practical results that ay emerge from surveys carried on in this warehouse over an extended period, e opportunity for junior staff to study insects in their natural surroundings ovides a most stimulating incentive to their laboratory investigations.

2. Work has begun on a survey of the mites to be found in cheese factories d stores in this country. The work is being undertaken by an officer who has d considerable experience of cheese infestation in New Zealand.

3. There is some reason to believe that birds may play a significant part in e distribution of b[illegible]th "stored products" and "domestic" insects. Experi-ents have been [illegible]ined to investigate this point, and during the autumn and nter of 195[illegible] [illegible]ly has been made of the insect fauna of birds' nests built or near bu[illegible]gs. The work is not yet complete, but sufficient has been complished to show that such nests often contain a surprisingly large number insect pests, a[illegible]ng them being larvae of clothes moths and carpet beetles.

OVER-WINTERING OF HOUSEFLIES

We are pleased to note that the Laboratory is collaborating with industry i an investigation of the over-wintering habits of houseflies; this is a matte about which there is still uncertainty and which has an important bearing on th planning of control measures.

SHORT-TERM INVESTIGATIONS ON INSECTICIDES

A considerable number of investigations on immediate practical problem have been carried out by the Insecticide Section. The following example are typical :—

1. Work has shown that the effectiveness of a combined pyrethrum + benzene hexachloride spray varies with different species of insect. It is par ticularly toxic to the Flour Beetle, *Tribolium castaneum.*

2. The pronounced synergistic action of piperonyl butoxide on pyrethrum has been confirmed for several stored products insects, but the work has no shown any increase in toxic life of the pyrethrum + piperonyl butoxide spray over pyrethrins alone, as has been claimed.

3. Wettable powders containing respectively DDT, BHC, aldrin and diel drin have been applied experimentally to bricks, and the residual toxicity o the insecticidal film has been assayed biologically. Two of the preparation have retained their toxicity for 10 months, others had lost it in periods varying from 4 months to 35 days.

The persistence of residual films of pyrethrum has been tested on a variety of different packing materials; such films have a short life under norma conditions in a warehouse and repeated treatments are necessary. Contrary to expectation, repeated application on softwood samples did not produce films more toxic or persistent than those first laid down.

4. Following laboratory work, a test has been made in a large granary of pyrethrum powder applied to the surface of a bulk of grain for the contro of the moth *Ephestia elutella.* For various reasons the results were not absolutely conclusive, but were sufficiently promising to warrant the repetition of the test next year.

FUMIGATION OF BULK GRAIN WITH CARBON TETRACHLORIDE

A method for fumigating existing bulks of grain has become increasingl desirable, and following reports from Canada that carbon tetrachloride migh be used for this purpose, a careful investigation of this method has been mad by the Laboratory. Full-scale tests have shown that even penetration of th fumigant can be obtained throughout the contents of a large silo bin by applyin the fumigant to the surface of the grain, and the method is now in use by th Ministry of Agriculture and Fisheries. Care must be taken to protect operative against toxic effect.

RESISTANCE OF HOUSEFLIES TO DDT

The high resistance of houseflies to DDT in certain parts of the world acquired by repeated exposure to the insecticide, affords an excellent opportunit for studying the mode of action and, possibly, the natural tolerance of certai other insects to this insecticide. The use of radioactive tracer techniques ha made it possible to demonstrate that resistant flies are able to decompose a

proportion of the DDT into non-toxic derivatives, and that normal, susceptible, flies are not able to do so. This is in agreement with current American work, but it is by no means certain that this phenomenon provides the complete explanation of the problem.

OVERSEAS LIAISON

We are glad to record that the Laboratory has maintained and increased its contacts with workers overseas.

Mr. T. A. Oxley and Miss M. B. Hyde attended the 7th International Botanical Congress in Stockholm, where Miss Hyde read a paper on her work on the sub-epidermal fungi of wheat grains. Subsequently they visited several research institutions, mills and grain storage installations in Sweden and Norway.

We congratulate Mr. Oxley on the award of a Nuffield Foundation Fellowship, under which he is spending the best part of a year in Australia and New Zealand studying grain storage problems.

We regret that it has not yet been possible to recruit a Colonial Liaison Officer, whose appointment was foreshadowed in our last report. Nevertheless increasingly close contact is being made with Colonial workers, both by correspondence and, we are glad to note, by personal visits.

During 1950 representatives from the following Commonwealth and other countries visited the Laboratory :—Australia, Burma, Canada, Cyprus, Egypt, France, India, Israel, Kenya, New Zealand, Nigeria, South Africa, and Tanganyika.

LIAISON WITH OTHER DEPARTMENTS

MINISTRY OF AGRICULTURE AND FISHERIES (INFESTATION CONTROL DIVISION)

We are glad to record that collaboration between the Laboratory and the Infestation Control Division has continued on the same close and informal basis as heretofore. Of particular value to the Laboratory has been the allocation, already mentioned, of a large " mixed " warehouse for general survey work and the observation of insect populations under natural conditions.

The Division has also arranged for a newly recruited member of the Laboratory staff to gain some practical experience, with its inspectors, of infestation control work.

COLONIAL OFFICE

The Director has continued to represent the Laboratory on the Stored Product Research Sub-Committee of the Colonial Office. Mr. R. W. Howe has returned to the Laboratory after two years spent in Nigeria with the Colonial Office team sent there to organize the control of stored products infestation. As was expected the experience that he has gained is already proving most useful and is providing a stimulus for new and interesting lines of research.

OTHER DEPARTMENTS AND PUBLIC BODIES

During 1950 advice or help has been given, on a wide variety of subjects, to a number of other Departments and public bodies, including the War Office, Admiralty, Metropolitan Police, Ministry of Food, Ministry of Health, Ministry of Supply, British Transport Commission and the Overseas Food Corporation.

PUBLICITY

During 1950, 16 papers have been published in scientific journals and 18 lectures and broadcast talks have been delivered. (See Appendix I.)

A film entitled " Insect Pests in Food " has been made for the Department by the Crown Film Unit. The Infestation Control Division of the Ministry of Agriculture and Fisheries collaborated closely in the preparation of this film.

ORGANIZATION

The biochemical research on the reaction of fumigants with foodstuffs has now been linked to the radioactive isotope tracer work, the staff involved forming a Biochemistry Section under the leadership of Mr. F. P. W. Winteringham.

ACCOMMODATION

It is a matter of regret to us that it has not yet been possible to start work on the new laboratories, the plans for which were mentioned in our last report. These buildings are urgently needed and we trust that the start will not be much further delayed.

J. L. SIMONSEN,
Chairman

June, 1951.

REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH FOR THE YEAR 1950

BIOLOGY

During 1950, as in previous years, the Biology Section has given special attention to studying the survival and rates of development of various pests in relation to temperature and humidity conditions. Information of this sort is gathered both from laboratory experiments and from the literature, and is summarised in graphical forms convenient for quick reference and for showing clearly the extent and limits of the available data. As an example of this, Fig. 1 summarizes the results of work in recent years at this Laboratory on the development and survival of the Australian Spider Beetle, *Ptinus tectus*. It

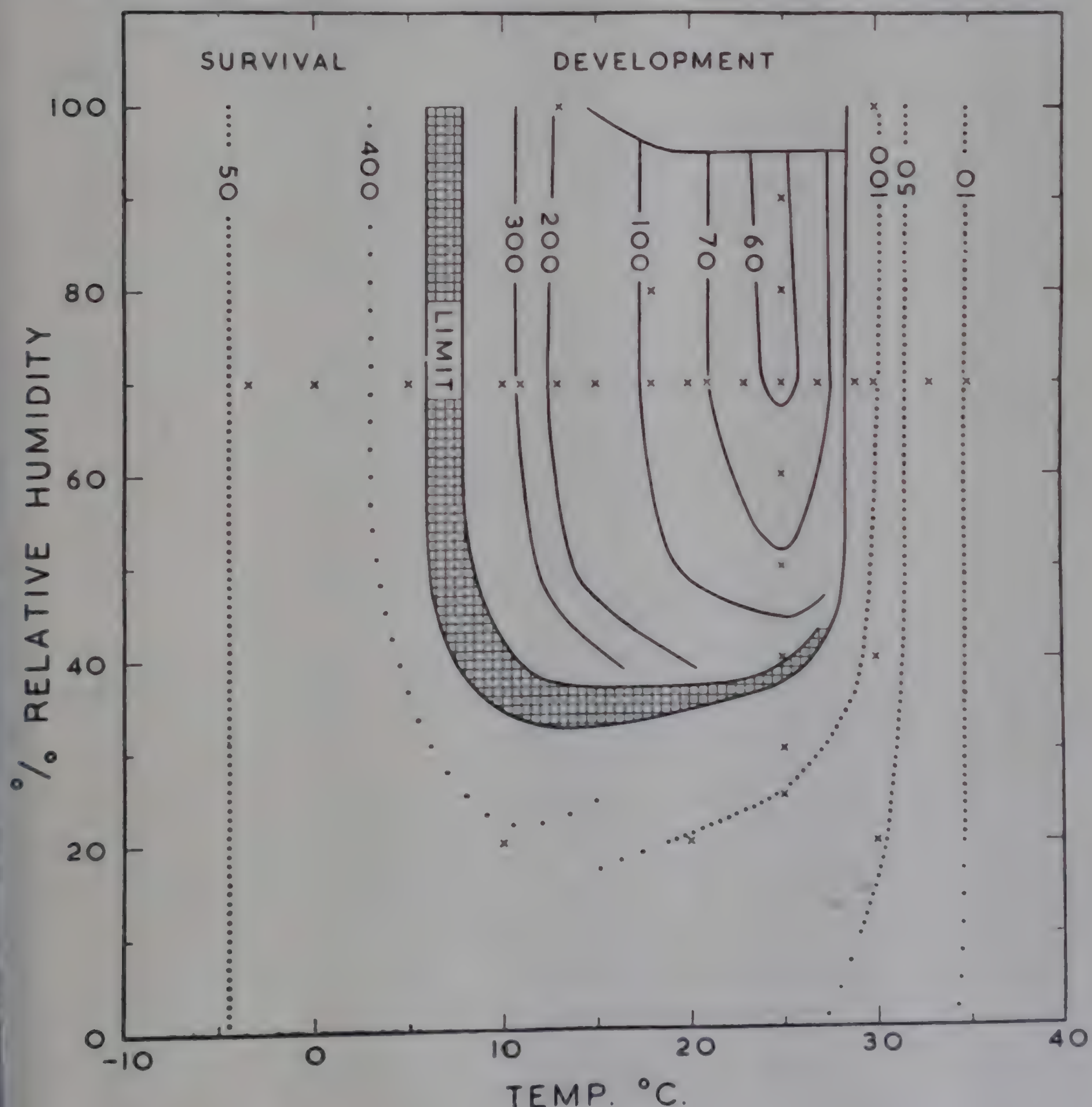


FIG. 1

Graph showing speed of development and duration of survival period of the Australian Spider Beetle, Ptinus tectus, *at different combinations of temperature and relative humidity.*

shows the limits of temperature and humidity beyond which complete development does not occur, the development periods under various conditions within these limits, and the survival periods of the most resistant stages when exposed to various conditions beyond the developmental limits.

Work in the field has included four new projects: an investigation of birds' nests as a source of " stored products " pests, a survey of mite populations on cheese, a study of the grain beetles of the genus *Oryzaephilus* in storage places, and an investigation of the residual populations which live semi-permanently in the recesses of storage buildings. [This choice of subjects is partly a measure to keep the laboratory work in its perspective as a subsidiary, though a most important one, to the study of the pests under their normal conditions of existence in the warehouse and in outdoor habitats.]

Mr. R. W. Howe has returned to the Section after two years in Nigeria, where he was concerned with problems of groundnut storage. As mentioned in the Board's Report, his experiences have emphasized the value of many of the major lines of work of the Laboratory, including that on the life history and physical limits of pests. Mr. Howe made a number of observations on pests of groundnuts which suggest lines of work for the future; for example, of the two very widespread species of flour beetle, he found that *Tribolium confusum*, although considered to be a native of Africa, seems to have been replaced in Nigeria by *Tribolium castaneum*, of Indian origin; and again, the outcome of competition between *T. castaneum* and the Khapra Beetle, *Trogoderma granarium*, seems to depend largely on climatic factors, so that under conditions warmer and drier than 33°C. and 50 per cent relative humidity, *Trogoderma* has the upper hand. Mr. Howe also demonstrated in Nigeria that *T. castaneum* attacking groundnuts is responsible not only for a considerable loss of weight, but also for a serious deterioration in quality, by causing an increase in the free fatty acid content of the nuts. A continuation of this work in the Pest Infestation Laboratory has shown that *Trogoderma granarium* causes similar damage.

Occurrence, Distribution and Activity of Pests

BIRDS' NESTS AS A SOURCE OF PESTS

Although there are many published records of the occurrence and breeding of " stored products " insects in birds' nests, they will support few definite conclusions, particularly as regards Britain. A survey begun this year has already produced much new information.

The nests found to support storage and domestic pests are those which are protected from rain; exposed nests decompose and support a non-pest fauna, characteristic of humus. The main group of protected nests is found in association with buildings. The large, dirty nests of house-sparrows usually harbour very large numbers of pest insects and mites, and considerable numbers are also found in nests of starlings, house-martins, and swallows. Pigeons' nests, consisting chiefly of guano, support an abundant and characteristic pest fauna.

Larvae of the following " stored products " pests have been found abundantly in a high proportion of suitable nests :—

Brown House Moth, *Hofmannophila pseudospretella;*
White-shouldered House Moth, *Endrosis lactella;*
Case-bearing Clothes Moths, *Tinaea pellionella,*
Tinaea columbariella;

Carpet Beetle, *Anthrenus sp.;*
Fur Beetle, *Attagenus pellio;*
Mealworm, *Tenebrio molitor;*
White-marked Spider Beetle, *Ptinus fur* (also adults).

London pigeons' nests contained large numbers of adults and larvae of :—
Bacon Beetle, *Dermestes lardarius;*
Mealworm, *Tenebrio molitor;*
Australian Spider Beetle, *Ptinus tectus;*
Biscuit Beetle, *Stegobium paniceum.*

Also among the fauna of nests protected from rain are large numbers of mites, notably the pests *Glycyphagus domesticus* and *Tyrophagus tenuiclavus*, and a number of species predatory on other mites or on the younger stages of insects.

Hymenopterous parasites of moth larvae are commonly found; also the bug, *Lyctocoris campestris*, and the larvae of the fly, *Scenopinus fenestralis*, both of which are predators of moth larvae.

It is noteworthy that the clothes moth *Tinaea columbariella*, although abundant in the nests, had not been recorded from Britain before, no doubt because this species had been confused with *T. pellionella* which it closely resembles.

A paper describing this work is in the press. It is proposed to continue until a fairly complete assessment of the fauna has been made, including any important regional differences within Britain; for it is clear that birds' nests are an important reservoir of pests, which presumably spread into houses and food stores. (*G. E. Woodroffe, B. J. Southgate.*)

HABITS AND BEHAVIOUR OF CARPET BEETLES

Observation of the seasonal occurrence and habits of *Anthrenus* spp. has been continued. A move out of doors in early March, 1950, was suggested by the discovery of adults on the inside of closed windows. In culture at 25°C., some of these beetles gave rise to a second generation of adults in eight months. In May, June and July, adults of *A. verbasci, A. fuscus* and *A. museorum* were common on flowers, especially Hogweed or Cow Parsnip (*Heracleum spondylium*) Wild Chevil (*Chaerophyllum sylvestre*) and Meadow-sweet (*Filipendula ulmaria*). However, they were very seldom found on any flowers situated more than 50 or 100 yards from houses or other buildings, and flowers very close to houses tended to have more beetles than those a few yards further away.

The behaviour pattern which leads the beetles to go into houses, birds' nests, etc., and lay eggs remains to be elucidated. In laboratory experiments with *A. verbasci*, all the adults tested moved from dim into bright light or towards a source of light while all the larvae showed the opposite reactions. Further behaviour experiments are in progress. (*Miss G. M. Skellon.*)

EFFECT OF CONSTANT AND FLUCTUATING TEMPERATURE ON *Calandra granaria*

Experiments have been carried out on the rate of development of *Calandra granaria* at constant temperatures ranging from 20° to 35°C. The rate of development was calculated on the period of time between egg-laying and emergence of adult. With temperatures up to 31°C., the rate of development was found to increase with each degree rise of temperature; between 31° and 34·5°C. there was a gradual fall in the rate, but at 35°C., i.e., only 0·5° higher, adults completely failed to emerge.

At present, experiments are in progress to determine the effect of fluctuating temperatures on the rate of development. The insects are kept alternately at temperatures above the limit of survival and temperatures well within the developmental range. (*Miss M. K. Winckler.*)

MITES ON CHEESE

Work has begun on a survey of the Tyroglyphoid mites to be found on imported and home-produced cheese. This involves a study of the different types of cheese and the curing and storage methods employed. The mites so far collected are:—

Tyroglyphus farinae, *Tyrophagus*, two or more species, *Carpoglyphus lactis*, *Tyrolichus casei*, *Glycyphagus domesticus*.

It is hoped to find an explanation of the abundance of these species relative to each other, in terms of the foodstuffs (including moulds), humidity, temperature, competition, or other factors. Special attention is being given to mites of the genus *Tyrophagus*, with a view to clarifying the systematics of this group and finding to what extent the variations depend on environmental conditions. Previous experience gained in the study of cheese-mites in New Zealand is being drawn upon usefully in developing this work. (*Miss P. L. Robertson.*)

IMPORTATION OF INSECTS

By courtesy of the Infestation Control Division of the Ministry of Agriculture and Fisheries, their records of insects found on ships importing stored produce from West Africa are being examined to discover which pests are being brought in and in what numbers. The most frequent importations are :—

Rust-red Flour Beetle, *Tribolium castaneum;*
Dried Currant Moth, *Ephestia cautella;*
Copra Beetle, *Necrobia rufipes;*
Khapra Beetle, *Trogoderma granarium;*
Cigarette Beetle, *Lasioderma serricorne.*

Further information is needed concerning the ability of these species to over-winter and their rate of increase in Britain.

Imported specimens of the genera *Laemophloeus* and *Oryzaephilus* (grain beetles) are being identified to establish the world sources of species. (*R. W. Howe.*)

Physical Limits

LIMITS FOR DEVELOPMENT AND SURVIVAL OF THE FLOUR MITE

To complete the study of the life-history of *Tyroglyphus farinae* over the full range of physical conditions which it will tolerate, it has been necessary to determine the temperature and humidity limits for complete development.

At 32°C., there is 100 per cent mortality in the egg stage or immediately after it. At 31°C., about 1 per cent succeed in completing development if the humidity is high (90 per cent relative humidity). At 30°C., some mites develop at humidities down to 72·5 per cent but none at 70 per cent relative humidity. At favourable temperatures of 10° to 20°C., some mites develop from egg to adult at humidities as low as 62·5 per cent, but eggs do not hatch at 60 per cent relative humidity.

Tyroglyphus is fairly well adapted to low temperatures. At humidities over 65 per cent, a proportion of the mites succeed at 5°C., but take over 5 months for complete development; they probably do not develop appreciably at 0°C., although they can live for long periods at this temperature. (*A. M. Cunnington, Mrs. J. M. Bond, Miss S. R. Wiley.*)

LETHAL HEAT TREATMENT FOR GRAIN INSECTS

Experiments are being carried out to determine the minimum heat treatment required to kill the commoner grain insects. Although this method of control has often been recommended, the published data on the heat resistance of the insects concerned are inadequate for a determination of the minimum heating required.

The method being used is to immerse small vessels of grain containing the insects in a thermostatically controlled hot water bath, fitted with a stirrer. The insects tested include adults and younger stages of:—

Lesser Grain Borer, *Rhizopertha dominica;*
Flat Grain Beetle, *Laemophloeus minutus;*
Saw-toothed Grain Beetle, *Oryzaephilus surinamensis;*
Merchant Grain Beetle, *Oryzaephilus mercator;*
Grain Weevil, *Calandra granaria;*
Rice Weevil, *Calandra oryzae;*
Angoumois Grain Moth, *Sitotroga cerealella;*
Flour Beetles, *Tribolium confusum* and *Tribolium castaneum.*

Although this series of experiments is unfinished, it seems very probable that exposure to 60°C. for 10 minutes will kill all stages of *Rhizopertha*, and that all the other species are killed by 10 minutes at 55° or 8 hours at 48°C. These treatments are less severe than those often prescribed, and, allowing for the fact that the whole mass of grain must be brought to these temperatures for the periods indicated, there seems to be a good working margin between the treatments necessary to kill the insects and those which would damage the grain. (*Miss B. E. Adamson, Miss E. A. Myerscough, M. E. Solomon.*)

LETHAL HEAT TREATMENT FOR CLOTHES MOTHS

As reported in "Pest Infestation, 1949," it has been shown that all stages of the common Clothes Moth, *Tineola bisselliella*, can be killed by an exposure of 4 hours at a temperature of 41°C. and a relative humidity of 70 per cent.

The possibility of turning this susceptibility to high temperatures to practical use has been investigated, and a number of practical tests have indicated, for example, that certain equipment now sold for drying clothes can produce the temperatures necessary for the disinfestation of garments, blankets, etc., attacked by this Clothes Moth. It has also been found possible in some cases to heat airing cupboards and small rooms to the same lethal temperature for this purpose.

LETHAL HEAT TREATMENT FOR CARPET BEETLES

In a water bath similar to the one used in the above experiments, the high temperature limits of the Varied Carpet Beetle, *Anthrenus verbasci*, are being investigated. It is clear from the preliminary results that this pest is a good deal

more resistant to heating than the Clothes Moth. (Annual Report, 1949, p. 7.) (*Miss G. M. Skellon.*)

RESISTANCE OF FLOUR BEETLE TO COLD

Further work on the resistance of the Rust-red Flour Beetle, *Tribolium castaneum*, to low temperatures has shown that the eggs and pupae are very susceptible to exposure at $-1°$ to $-3°$C., and survive for less than a day at these temperatures. Young adults die in two days. Larvae become more resistant as they develop and the oldest survive for more than five days. (*K. I. Street, H. D. Burges.*)

RESISTANCE OF DRIED CURRANT MOTH TO COLD

Continued laboratory experiments on the effects of low temperatures on *Ephestia cautella* have shown that larvae are more resistant than eggs ; pupae may be a little more resistant than larvae under certain conditions. The mortalities following various exposures are shown in Fig. 2. A temperature of 13°C. is low enough to prevent development from the larval to the adult stage.

In over-wintering experiments like those in the following section some larvae survived the winter of 1949-50 in all except the most exposed positions used. This work has been done in conjunction with that of Mr. G. A. Brett, of the Infestation Control Division, Ministry of Agriculture and Fisheries. (*H. D. Burges.*)

OVER-WINTERING OF STORAGE PESTS

Further information on the ability or failure of some fifty species to survive the winter in various situations was gathered from the exposure of cultures throughout the winter of 1949-50. A similar series is being undertaken in 1950-51.

Some of the species involved can overwinter in many out-door situations ; this includes those species found in birds' nests. There are others which cannot overwinter except in heated buildings or in other situations which remain warm throughout the year. There is also a considerable group of those which succeed or fail in overwintering according to the severity of the winter and the degree of protection from severe cold which their surroundings may afford ; other factors, such as the degree of suddenness of the first cold spells, may also be important. To give a firm basis for classifying all the relevant species in this way, and to provide clear information about the cold-resistance of each one, further experiments are required.

An integral part of the above work is the recording of temperature conditions in the situations concerned. The degree of protection from cold afforded by different types of buildings and stored materials is being investigated. (*Miss B. E. Adamson, Miss E. A. Myerscough, M. E. Solomon.*)

Life Histories

The study of the rate of development, egg output and mortality under different physical conditions, and sometimes on different foodstuffs, is essential to an understanding of rise and decline of infestations, and often essential for making predictions about particular situations. However, the collection of such information involves a great deal of work on each species.

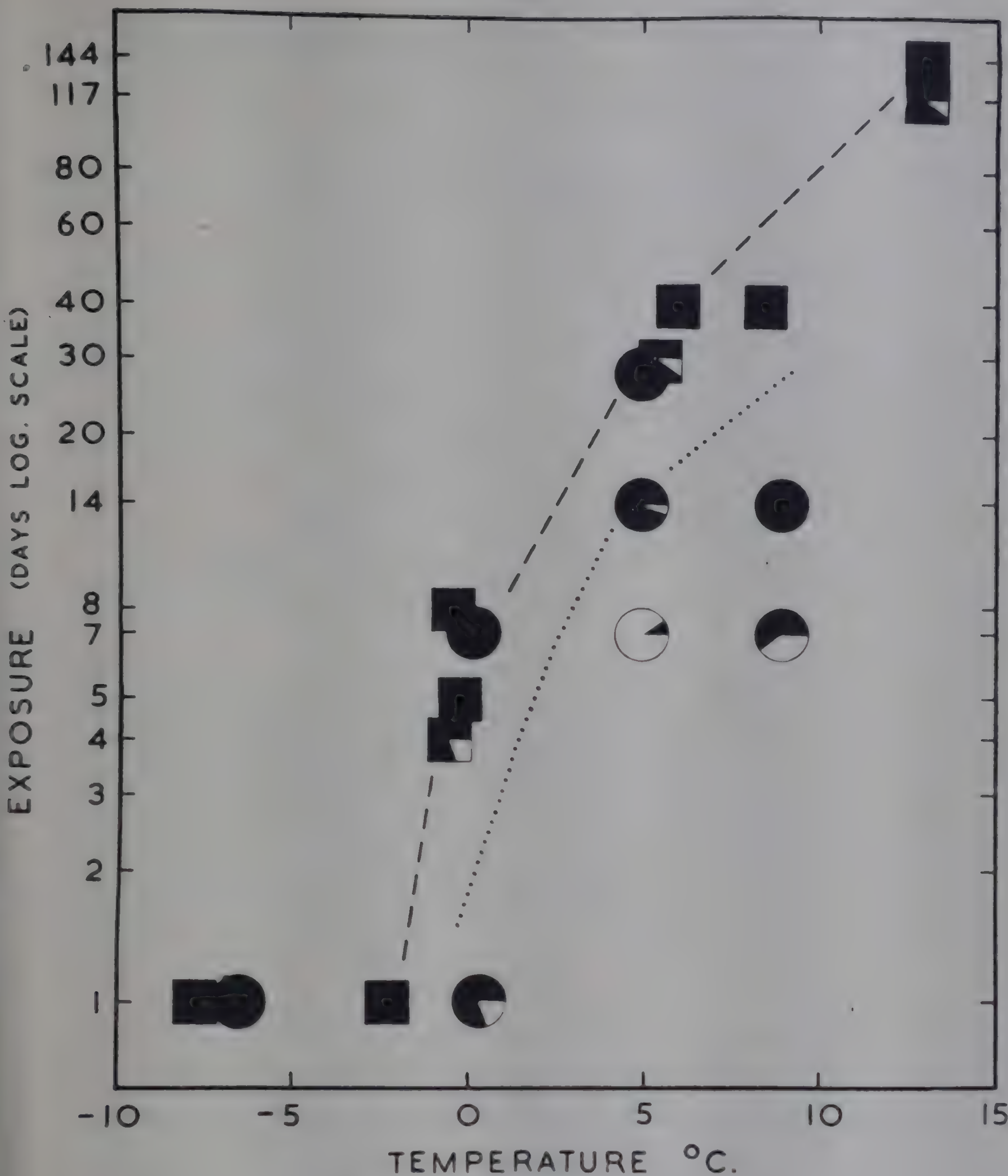


FIG. 2

Graph showing the resistance of eggs (circles) and larvae (squares) of Ephestia cautella *to cold. The shaded area of the squares and circles is proportional to the mortality.*

An unusually complete set of data of this sort has now been accumulated for the Flour Mite, *Tyroglyphus farinae*. These figures are at present being analysed and used to calculate the corresponding net rates of increase. It is proposed to use this, and other information arising from the experiments, in later studies on populations under storage conditions. (*A. M. Cunnington, Mrs. J. M. Bond, Miss S. R. Wiley, M. E. Solomon.*)

The work on Spider Beetles (*Ptinidae*) is being continued on a reduced scale. During the year, fresh information has been gained from experiments on *Gibbium psylloides*, *Niptus hololeucus* and *Mezium affine*. (*R. W. Howe, H. D. Burges.*)

Earlier work on the Saw-toothed Grain Beetle, *Oryzaephilus surinamensis*, and the Merchant Grain Beetle, *O. mercator*, is now being continued. These insects develop very rapidly in less than a month at 25° to 35°C. (*Miss J. E. Currie, R. W. Howe.*)

Work has begun on a study of the development of the Varied Carpet Beetle, *Anthrenus verbasci*, at a series of temperatures and humidities. (*Miss G. M. Skellon.*)

It is proposed to make similar studies upon two other species of Anthrenus, namely, *A. fuscus* and *A. museorum*, also upon several moths of the genus *Tinaea*. A little further work on the factors influencing the diapause or resting phase of the larva of the Brown House Moth, *Hofmannophila pseudospretella*, has been done, but it has had to be temporarily set aside. (*G. E. Woodroffe, B. J. Southgate.*)

Improvements in Laboratory Techniques

ESTIMATION OF INFESTATION BY MEASUREMENT OF CARBON DIOXIDE

Factors influencing the accuracy of the carbon dioxide method for estimating the animal life in samples of grain have been re-examined.

The samples are normally incubated at 25°C. The amount of carbon dioxide produced depends on temperature; if the grain is incubated at 17°C. the carbon dioxide produced is 45 per cent less than at 25°C; at 28°C. it is 30 per cent more, and at 33°C. it is 75 per cent more. Insects which have been in cool conditions gradually acclimatize themselves to the higher incubation temperature. A period of one day for conditioning to the incubation temperature is therefore required. The accumulation of carbon dioxide reduces the activity of insects; this effect becomes detectable when the concentration of carbon dioxide is about 4 per cent, and is marked at concentrations of 10 per cent or more.

CONTROL AND MEASUREMENT OF HUMIDITY

Information about techniques and recent data relating to the control of humidity in laboratory work has been set out in a paper which is in the press.

Improvements have been made in the method of measuring humidity colorimetrically with papers impregnated with cobalt thiocyanate. In collaboration with the Tintometer Company a method has been devised whereby the test papers, immersed in oil, may be matched against coloured glass standards. (*M. E. Solomon.*)

GRAIN STORAGE AND MYCOLOGY

LIAISON WORK WITH THE COLONIES

Enquiries from the Colonies relating to grain storage have continued to be received, but the appointment of the Liaison Officer mentioned in last year's report has not yet been made, and therefore this work has not expanded as much as was envisaged. (*T. A. Oxley.*)

SUBEPIDERMAL FUNGI OF WHEAT GRAINS

The preliminary identifications of the subepidermal fungi made last year have been confirmed by more extensive culturing from surface-sterilized wheat

grains. *Alternaria tenuis* was by far the commonest internal fungal species isolated, occurring in 64·4 per cent of the grains examined. Bacteria (28·8 per cent), *Mycogone* sp. (?) (7·7 per cent), *Cladosporium herbarum* (5·8 per cent), *Pullularia pullulans* (4·8 per cent), *Botrytis cinerea* (1·9 per cent), *Fusarium* sp. (1·9 per cent) and *Stemphylium botryosum* (0·9 per cent) were also isolated.

The mycelium is first observed in the grain at a comparatively late stage of development, and its spread during the next few days, during which the grain is drying out rapidly, seems to be finally restricted by the drying of the grain as ripening proceeds.

The method of entry of the subepidermal mycelium is not yet established. Spores of many of the species given above are commonly found on the outside of the grain and among the dead floral parts, indicating that the internal mycelium may originate from external hyphae penetrating the epidermis. Isolations of the same fungi, and in approximately the same proportions as they are found in the grains, from surface-sterilized stems, suggests however that the subepidermal mycelium may arise from an upgrowing systemic infection of the wheat plant. A dual origin therefore appears possible. (*Miss M. B. Hyde, Mrs. H. B. Hollier, D. Budd.*)

RESPIRATION OF FUNGUS-FREE WHEAT

A conductometric method of measuring the small quantities of carbon dioxide produced during the respiration of dormant wheat of relatively low moisture content has been satisfactorily developed. Preliminary experiments indicate that the respiration of normal grain, which increases with increasing moisture content, is noticeably greater than that of fungus-free grain produced by spraying the developing ears with 8-hydroxy quinoline sulphate as described in last year's report. (*Miss M. B. Hyde, G. Ayerst.*)

MYCOLOGICAL PROBLEMS OF FOOD STORAGE

From time to time mycological investigations have been carried out on various foodstuffs in storage. These include a series of experiments showing that the growth of fungi and bacteria in a damp mass of maize results in heating (with recorded temperatures as high as 62°C.) and eventual blackening of the grains. The success of heat treatment for the control of an extensive mould growth on stored prunes was also checked by a number of inoculation experiments. (*Mrs. H. B. Hollier, G. Ayerst.*)

FIELD WORK ON GRAIN STORAGE

There has been a considerable increase in the amount of field work during the year. The amount of advice given and the number of lectures have also increased.

An experiment to determine the efficiency of a supposedly self-ventilating silo bin filled with wheat on a farm has been started, and is still in progress.

Ten thermocouple ropes have been prepared for use and installed with the associated apparatus in silo bins in co-operative experiments with the Infestation Control Division of the Ministry of Agriculture and Fisheries.

A large scale experiment on the outdoor storage of barley in sacks is also in progress, in co-operation with the National Agriculture Advisory Service. (*T. A. Oxley, J. P. Heslop*).

INSECTICIDES

STATISTICAL ASPECTS OF INSECTICIDAL ACTION

A second paper has been published on the independent joint action of insecticides, covering in detail the statistical and experimental aspects of the method recommended for determining whether a mixture is as toxic as predicted. (*P. S. Hewlett.*)

PYRETHRUM-BHC SPRAYS FOR STORED PRODUCT INSECTS

It was reported last year that favourable interaction had been found with mixtures of pyrethrins and gamma-BHC in Shell oil P31 using the Flour Beetle, *Tribolium castaneum*, as the test insect. The value of such mixtures has been further investigated in laboratory tests with *T. castaneum* and four other species of stored product beetles. Wood blocks were sprayed with oil containing 0, 0·65, or 1·3 per cent w/v pyrethrins plus 0, 0·2, or 0·4 per cent w/v gamma-BHC, and beetles were then confined on the blocks. Table I gives a general appraisal of the results in a condensed form. Where varying the concentration had a considerable influence on the response, a range is given.

The entries for the combinations of pyrethrins and BHC are somewhat inadequate but are amplified in the " Remarks " column.

The favourable interaction between pyrethrins and BHC applied to *T. castaneum* was again observed, but no such interaction was apparent with the other species: nevertheless, the mixture might be useful against them, especially in mixed infestations. The following formulations in a refined heavy mineral oil are suggested for use against five of the common species of stored product beetles, on the assumption that the upper practical limits of concentrations of pyrethrins and gamma-BHC are 1·3 and 0·4 per cent respectively:—

For the Grain Weevils, *Calandra granaria* and *C. oryzae:* 0·2 to 0·4 per cent gamma-BHC; admixture with pyrethrins is unnecessary.

For Brown Spider Beetles, *Ptinus tectus:* 1·3 per cent pyrethrins; but the addition of 0·4 per cent gamma-BHC should improve the spray somewhat.

For Confused Flour Beetles, *Tribolium confusum:* 0·4 per cent gamma-BHC and 0·65 to 1·3 per cent pyrethrins.

For Red Flour Beetles, *Tribolium castaneum:* 0·2 to 0·3 per cent gamma-BHC and 0·65 to 1·3 per cent pyrethrins, or 0·4 per cent gamma-BHC alone.

Following reports from the Infestation Control Division, Ministry of Agriculture and Fisheries, that observations made during the application of control measures under practical conditions indicated that Saw-toothed Grain Beetles, *Oryzaephilus surinamensis*, were fairly resistant to BHC, the resistance of this species to gamma-BHC in P31 oil was compared with that of *Tribolium castaneum*. The BHC solution was applied as a film to filter paper and *O. surinamensis* was found to be much the more resistant. For example, when the BHC caused a 95 per cent kill of *T. castaneum*, it caused only a 5 per cent kill of *O. surinamensis*. However, films of 1·3 per cent pyrethrins in P31 killed *O. surinamensis* beetles at least as readily as they killed *T. castaneum*, although they did not knock the former down so easily. (*P. S. Hewlett, Miss B. Clayton.*)

PYRETHRUM-PIPERONYL BUTOXIDE SPRAYS FOR STORED PRODUCTS INSECTS

A considerable amount of work has been done on piperonyl butoxide. This substance is of very low toxicity to mammals but can greatly increase the toxicity

TABLE I

Summary of results from tests on the toxicity of films formed on wood by 0·65% pyrethrins$_3$ 1·3% pyrethrins, 0·2% BHC and 0·4% BHC, alone and in combination, in P31: 25°C. and 70% R.H.

Species of insect	Response	Insecticide			Remarks
		Pyrethrins	BHC	Pyrethrins +BHC	
Calandra granaria	Knock-down	Excellent	Excellent	Excellent	Addition of pyrethrins to BHC made no noticeable difference to knock-down or mortality.
	Mortality	Poor to fair	Excellent	Excellent	
Calandra oryzae	Knock-down	Good to excellent	Excellent	Excellent	Pyrethrins antagonize BHC slightly, but not sufficiently to matter.
	Mortality	Very poor	Excellent	Excellent	
Ptinus tectus	Knock-down	Good to excellent	Very poor	Excellent	Addition of BHC improves knock-down and mortality slightly. BHC alone very poor.
	Mortality	Very poor	Very poor	Poor to fair	
Tribolium confusum	Knock-down	Excellent	Very poor to good	Excellent	Performance of BHC sensitive to concentration.
	Mortality	Nil	Very poor to good	Poor to good	Pyrethrum knocks down, BHC kills.
Tribolium castaneum	Knock-down	Moderate to good	Moderate to good	Excellent	Outstanding favourable interaction between pyrethrins and BHC.
	Mortality	Very poor to fair	Moderate to good	Excellent	

of pyrethrins to insects. Pyrethrin-piperonyl butoxide mixtures appear very promising as cheaper substitutes for straight pyrethrum-in-oil sprays for the control of warehouse insects. Piperonyl butoxide has been shown to synergize pyrethrins in Shell oil P31 when tested on five species of stored product beetles. On the other hand, reports from the U.S.A. that the mixture was more stable than pyrethrins alone have not been confirmed; no such effect could be detected.

All the laboratory experiments have indicated that, under a given set of conditions, a mixture of pyrethrins and piperonyl butoxide may be regarded as equivalent in toxicity to a certain concentration of pyrethrins alone, higher than the concentration of this constituent in the mixture. Thus, under one set of experimental conditions, 1·3 per cent pyrethrins was equalled in toxicity by 0·4 per cent pyrethrins mixed with 2·5 per cent of piperonyl butoxide. However, the pyrethrin equivalent of a particular mixture may vary according to the species of test insect used and the method of application, e.g. film or direct spray. In this connexion, the pyrethrin equivalent of a given mixture applied as a film has been found to be lower for *Tribolium castaneum* than for *Calandra granaria*, *C. oryzae*, *Ptinus tectus*, and *Oryzaephilus surinamensis*.

Using *T. castaneum* as the test insect, the effect of mixing piperonyl butoxide with some insecticides other than pyrethrins has been investigated. Allethrin was synergized, but the tests were not sufficiently extensive to show whether the synergism was as great as with pyrethrins; gamma-BHC was synergized less intensely than pyrethrins; and DDT was antagonized in films, but not in direct sprays. (*P. S. Hewlett, Miss B. Clayton.*)

IMPREGNATION OF SACKING WITH PYRETHRINS AND PIPERONYL BUTOXIDE

A report was received from the U.S.A. that flour in cotton sacks impregnated with small amounts of pyrethrins, with or without piperonyl butoxide, was not infested during exposure for several months to a heavy infestation of various common stored product insects. The effect was apparently one of repellency, because beetles confined on the treated cloth were not killed.

Arrangements are now being made, in collaboration with the British Jute Trade Research Association, to impregnate jute cloth and test its protective effect against infestation of cereals kept in miniature bags made from it. Preliminary work with small impregnated pieces of jute fabric provided by the Indian Jute Mills Association Research Institute has shown that, at the highest level of treatment (20 mg. pyrethrins + 200 mg. piperonyl butoxide per square foot), the toxic effect against the Granary Weevil, *C. granaria*, and the Red Flour Beetle, *T. castaneum*, was insufficient to be of practical value. In these tests no essential difference was noted between hessian and twill materials as substrata for the impregnation, and repellency trials were therefore confined to the hessian. Allowing the insects a choice of treated or untreated cloth showed that the impregnated material was repellent to *T. castaneum*, but at no time was 100 per cent repellency observed. A similar test with the Brown Spider Beetle, *Ptinus tectus*, gave an approximately 50 : 50 distribution, whereas with *C. granaria*, the Saw-toothed Grain Beetle, *Oryzaephilus surinamensis*, and caterpillars of the Cacao moth, *E. elutella*, many more insects were counted upon the treated than upon the untreated cloth. These apparently contradictory results could be accounted for by an ortho-kinetic response depending upon how quickly the increased locomotor activity was cut short by loss of muscular co-ordination. (*Miss B. Edwardes-Evans, E. A. Parkin, P. S. Hewlett.*)

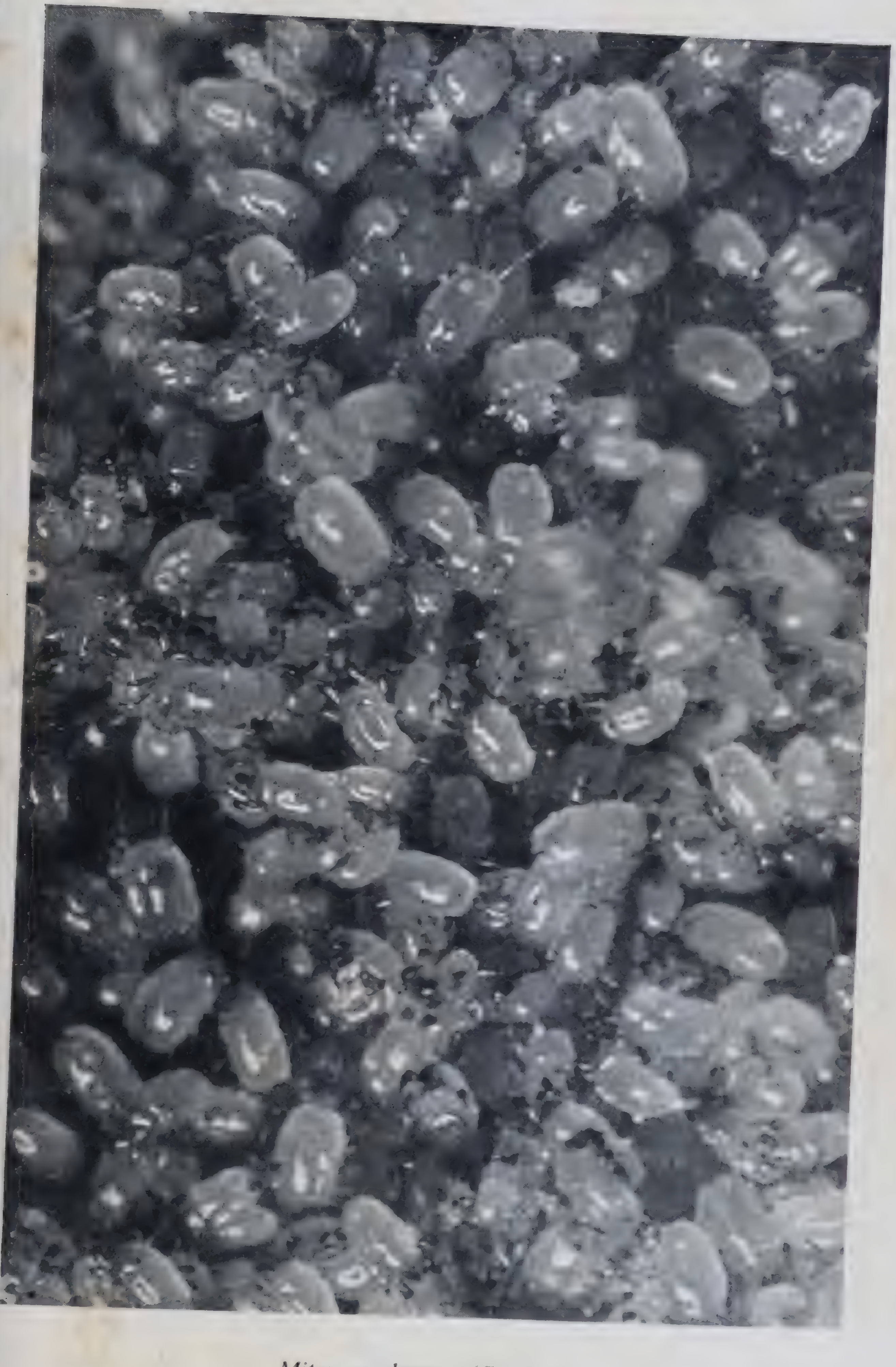
(A) *Experimental fumigation of silo bin. Spraying carbon tetrachloride on to the surface of the grain.* (*See page* 26)

(B) *Experimental fumigation of a loaded barge.* (*See p.* 25)

PLATE 1

Experimental fumigation of dried fruit. Injecting carbon dioxide into a tin of currants to sealing. *(See p. 28)*

PLATE 2



Mites on cheese. (*See p.* 8)

PLATE 3

Adult carpet-beetle, Anthrenus verbasci, *on Matricaria camomilla (magnification* × 10). (*See p.* 7)

PLATE 4

PERSISTENCE OF PYRETHRUM FILMS ON PACKING MATERIALS

The persistence of toxicity of films formed by 1·3 per cent pyrethrins in Shell oil P31 on different common packing materials has been investigated; tests have been made on samples from hardwood and softwood dried-fruit boxes, on different types of jute sacking, and on cardboard dried-fruit cartons. The hardwood and softwood, in the condition in which they are used commercially, supported films of similar persistence; the different types of sacking also supported films of about equal persistence. However, if films on wood are regarded as effectively insecticidal for 15-20 days, those on sacking would remain so for 2-4 days, and those on cardboard for less than 24 hours.

The effect of the roughness of the softwood on the persistence of the insecticidal film has been found to be considerable; the rougher the surface the less persistent is the film deposited on it. (*Miss B. Edwardes-Evans.*)

EFFECT OF REPEATED SPRAYING ON PERSISTENCE OF PYRETHRUM FILMS

Under practical conditions pyrethrum films usually have a fairly short life and repeated treatments are necessary. It was thought that this multiple application of insecticide might lead to the eventual building up of films more toxic or persistent than those formed first. However, no appreciable gain was noted when softwood samples were sprayed six times at monthly intervals with 1·5 mg./sq. cm. of 1·3 per cent pyrethrins in Shell oil P31. (*Miss W. M. Eustace.*)

RESIDUAL TOXICITY OF INSECTICIDAL FILMS ON BRICKS

Various materials available for application to surfaces in warehouses, etc., have been tested to compare their persistence. They were applied by pipette to Fletton bricks, the coatings allowed to dry, and the bricks stored at 25°C. and 70 per cent R.H. Flour Beetles, *Tribolium castaneum*, were confined on the coatings at intervals.

Wettable powders containing respectively 33 and 50 per cent DDT, and a 50 per cent DDT dispersion were applied at the rate of about 90 mg. DDT per sq. ft. A cement paint, containing an unknown concentration of DDT, was put on with a brush to give the sort of cover one would expect in practice. A wettable powder containing 6·5 per cent gamma-BHC was applied to give about 11 mg. of the toxic ingredient per sq. ft. Aldrin and dieldrin wettable powders and emulsions, all containing 25 per cent of active ingredient, were applied at both dosages specified above.

All the coatings were highly toxic to *T. castaneum* beetles initially, and all those formed from the DDT preparations and from the dieldrin wettable powder at the higher dosage have remained so for ten months. The coating of BHC wettable powder had lost its toxicity to the test insect in 35 days. Other things being equal, aldrin formed less persistent coatings than dieldrin; and the powders formed more persistent coatings than the corresponding emulsions. The coatings of aldrin powder lost their toxicity in about two months at the lower dosage and in about four months at the higher. The dieldrin powder at the lower dosage lost its toxicity in about ten months and so was more persistent than the aldrin powder at the higher. (*Miss W. M. Eustace.*)

PYRETHRUM POWDER FOR THE CONTROL OF THE GRANARY WEEVIL

Reports from East Africa have indicated that 0·25 per cent by weight of pyrethrum powder mixed into clean wheat will protect it from attack by *Calandra* and *Tribolium* over a period of eight months. Although pyrethrum is admittedly an expensive insecticide, it was pointed out that the cost of the treatment was very small compared with the nearly 50 per cent reduction in value of the untreated control grain.

A laboratory experiment has now been carried out to check these claims and find out more about the effect of the powder. The results showed that wheat was adequately protected at 25°C. against infestation by the Granary Weevil, *Calandra granaria*, by uniform admixture of 0·25 per cent or more by weight of pyrethrum powder containing 1·29 per cent pyrethrins. To bring about a reduction in the population of insects it is considered necessary for the powder to cause about 86 per cent knock-down of the weevils within 24 hours.

Three types of response of the beetles to the insecticides were recorded: the speed of knock-down, the speed of kill, and the numbers of first generation beetles which emerged, i.e., a measure of the reduction in reproductive capacity; the last criterion is obviously the one of greatest practical importance. The reduction in reproductive capacity was found to be much more closely related to speed of knock-down than to speed of kill. This is understandable, for oviposition by the Granary Weevil is a complex process involving drilling a hole in a grain with the mouth parts, reversing position to find the hole with the ovipositor, depositing the egg, and sealing the hole with a droplet of specially secreted fluid. Contact with the pyrethrum powder may so irritate the beetles that they find it hard to stand still long enough to complete the various phases of the process, or may cause sufficient deterioration of neuro-muscular co-ordination that weevils that have successfully bored a hole cannot find it with the ovipositor to deposit the egg. (*E. A. Parkin.*)

PYRETHRUM POWDER FOR THE CONTROL OF THE CACAO MOTH ON GRAIN

A study of the considerable amount of information available upon the habits of the Cacao Moth, *Ephestia elutella*, when it attacks wheat, showed that there were two points in the life-cycle at which insecticides might be particularly usefully employed. The moth rests on the surface of the grain to lay its eggs, and the fully grown caterpillar wanders over the surface of the grain in the course of its migration in search of a suitable site for pupation. Application of suitable insecticidal dust to the surface of the grain would thus seem an excellent way of taking advantage of the habits of this insect, and previous work by the Laboratory had shown that effective control can be obtained with surface application of alumina dusts. As these dusts are no longer available, pyrethrum powder has been tried.

Laboratory experiments showed that a 1·3 per cent pyrethrum powder was rapidly lethal to the moths and more slowly lethal to the caterpillars, although the latter quickly showed signs of convulsions. Dusted grain was exposed to moths and no breeding observed at dosages corresponding to approximately 1lb. or more of 0·9 per cent pyrethrum powder per 100 sq. ft. of grain surface: a few larvae were present in grain covered with 0·4lb. or less per 100 sq. ft. *Ephestia* caterpillars were placed about an inch down in grain the surface of which was then dusted with pyrethrum powder at various rates up to 1·9 lb. per

100 sq. ft. Moths were later found in all dishes, in decreasing numbers at the higher dosages, and it seemed that, at these higher dosage levels, the pyrethrum powder was sufficiently toxic but was not adequate in quantity to cover the grain. The method of application tended, in particular, to leave untreated spots round the margin of the dish.

The treatment was considered sufficiently promising for a practical trial but, if treatment was to be applied before *E. elutella* moth emergence began in the warehouse, it had to be applied without delay, thus leaving no time for more laboratory research. The opportunity was therefore taken to give an arbitrary surface treatment to a pile of 500 tons of wheat in bulk, floor storage. Arrangements for the selection and holding in store of the grain were made through the Infestation Control Division, Ministry of Agriculture and Fisheries. The rate of dosage of 1·14 lb. of powder per 100 sq. ft. was based on the laboratory work but proved rather low in relation to uniformity of coverage of the grain, especially in a stowage with many pillars and pipes running through it. Moreover, the level of endemic infestation was low, but although control of *E. elutella* on the treated area was not complete, it was evident that the dust had had a marked effect in keeping down infestation. It is hoped that an opportunity will occur in 1951 for a repetition of this experiment with a higher level of infestation and improved coverage by the dust. (*E. A. Parkin, Miss W. M. Eustace.*)

INSECTICIDAL SMOKE TREATMENT OF A FARM GRANARY

An opportunity arose to make a practical trial of the value of insecticidal smoke treatment of an empty farm granary. The whole building was first thoroughly cleaned by brush and vacuum cleaner. Gamma-BHC smoke generators were then ignited in sufficient numbers to give a dose equalling the highest recommended for the most resistant stored product insects. Sample counts during the following six days showed a high percentage kill of all insects which emerged from crevices during or after treatment. Saw-toothed Grain Beetles, *O. surinamensis*, were more difficult to control by this method than the numerous other species of insects present, but it was not clear how much this was due to greater resistance to the insecticide and how much to the greater ability of this species to avoid the insecticide by resting deeply in crevices.

Observation on the BHC treatment had to be curtailed because of the need for space to accommodate the new harvest. A DDT smoke treatment was therefore given at the dosage normally recommended for stored product insects and this markedly increased the numbers of insects killed, indicating that a considerable population of unaffected insects remained hidden away after the BHC treatment was given. Eight days after the application of the DDT smoke the kill of observable insects had reached 100 per cent and the floors were swept preparatory to the storage of the new harvest.

An inspection three months later revealed very few insects and these could well have been introduced on dirty sacks. (*E. A. Parkin, Miss W. M. Eustace.*)

BIOLOGICAL EVALUATION OF INSECTICIDAL RESIDUES IN CROPS

Samples of groundnuts and sunflower seeds from East Africa were sent to the Laboratory by the Agricultural Research Council acting on behalf of the Overseas Food Corporation, who wished to know whether any toxic residues were present in the seeds harvested from crops treated during growth with some of the

recently developed phosphorus insecticides. The Laboratory agreed to expose the seeds to insects which are common pests of groundnuts in store. One species of beetles and two of moths were used and no deleterious effect on the appearance of the insects or on their rate of reproduction could be detected. In the complete absence of any information on the toxicity to the insects of residue of the insecticides in question, however, the results cannot be accepted, without due caution, as meaning the absence of residues toxic to mammals. (*E. A. Parkin, Miss B. Clayton.*)

ACARICIDAL PROPERTIES OF INSECTICIDES

A preliminary investigation has been made, using a simple immersion technique and the Flour Mite, *Tyroglyphus farinae*, of the acaricidal value of the insecticidal sprays commonly used against insects in warehouses.

The base oil (P31) has been found to have little acaricidal effect and the speed of kill is not increased by the incorporation of 0·8 per cent w/v p, p^1 DDT. A solution containing 1·3 per cent pyrethrins was not much faster in action. Gamma-BHC, Lethane 384, and piperonyl butoxide were all strongly acaricidal, with relative potencies in the approximate ration 6 : 3·5 : 1 respectively. In view of its low mammalian toxicity and slight, mild odour, piperonyl butoxide at 2 to 5 per cent in P31 should be worth practical trial under circumstances where taint must be avoided, e.g., in cheese or flour stores. (*E. A. Parkin.*)

MICRO-DROP APPLICATOR

An apparatus for applying minute drops of liquid insecticide to a selected area on an individual insect has been designed: it has been constructed by the Laboratory's instrument maker. Applicators have previously been built in this country to work on the same principle; namely, the expulsion of minute quantities of a liquid from a hypodermic syringe of narrow bore by depressing the plunger with a micrometer-screw head, actuated in turn through a reduction gear, then blowing the droplet from the tip of the hypodermic needle by a puff of air. However, this model is thought to have some special advantages. A simple device has since been added for repeating semi-automatically the discharge of a given volume of liquid from the syringe. The arrangement for blowing the drops from the tip of the needle has some original features, including modifications of the shape of the tip, which allow high directional precision in firing drops down to 0·015 cu. mm. in volume. It is hoped with further experience to reduce this limit.

In order that they may be treated quickly with the micro-drop applicator, a special technique has had to be developed for holding small crawling insects, e.g. *Tribolium castaneum* beetles (3·5 mm. long), so that the droplets hit the desired part of the body. A suction method of handling has been used successfully, thus avoiding anaesthetization. (*P. S. Hewlett.*)

MOTHPROOFING TESTS

Experiments in connexion with the preparation of a specification for a standard test of mothproofing agents, which is being undertaken in conjunction with three other Laboratories represented on the Larval Test Sub-Committee of the Moth and Dermestid Beetle Proofing Committee, have continued throughout the year. Much of the work has been concerned with the factors influencing

rate of larval growth, such as type of breeding medium, different strains of moths, and small differences in the temperature of breeding. This last factor appears to be very important and work is still in progress upon it. The Sub-committee is now in process of drafting a provisional specification. (*E. A. Parkin, Mrs. P. J. Maycock, Miss D. G. Blackman.*)

CONTROL OF CLOTHES MOTHS

In the latter half of the year a programme of laboratory research into the control of clothes moths was drawn up to include:—

(a) a study of the effect of insecticides applied as dusts and sprays against the common species of clothes moths and house moths;

(b) the testing of various chemicals as repellents to moths and their larvae;

(c) testing the effect on moths and larvae of the vapours of such chemicals as naphthalene and paradichlorbenzene;

(d) a study of the effect of brushing, exposure to sunlight, vacuum cleaning etc., as measures of prevention and control;

(e) the testing of the efficacy of various mothproofing agents in providing protection against larval attack both before and after simple laundering, dry cleaning, and light exposure tests.

As a basis for this programme a stock of the Webbing Clothes Moth, *Tineola bisselliella*, is being bred under standardized conditions, i.e. at 25°C. and 70 per cent R.H. and at a fixed population density on scoured wool yarn impregnated with debittered yeast and cholesterol, so that larvae of known age can be obtained as required,

Larvae 20 and 25 days old have been exposed at 20° and 25°C. to dusts containing 0·9 per cent pyrethrins; 1·5, and 10 per cent technical DDT; and 1 and 5 per cent gamma-BHC. There was little difference in speed of action of the various concentrations of DDT or BHC respectively; little difference due to the temperature of exposure; and no marked effect due to age, although the older larvae tended to be slightly more resistant. The pyrethrum powder caused the most rapid knock-down (100 per cent in 15 minutes) and the gamma-BHC powders the fastest kill (100 per cent in 24 hours).

An experiment is in progress to determine the degree of protection to wool cloth afforded by various methods of wrapping and sealing, when the source of infestation is free-flying moths. (*Mrs. P. J. Maycock, Miss D. G. Blackman.*)

ATTRACTANTS AND REPELLENTS

A brief account was given in the Annual Report for 1949 of the construction of an olfactometer for testing the olfactory responses of the Greenbottle fly, *Lucilia sericata*. Testing of this apparatus has continued and a number of improvements have been effected. Experiments with known repellents such as citronella oil and wintergreen oil, and with attractants such as ammonia, have been carried out. Good responses to repellent substances were obtained, but it was found more difficult to obtain a satisfactory reaction to attractants, largely because of the very low concentrations required in the atmosphere before insects found the odour attractive. Partly because of these difficulties, partly because of the great expenditure of time required for each test, and partly because of lack of staff to help on the chemical side of this study, the priority of this work has

been reduced in favour of the project on the control of clothes moths. Tests will be carried out intermittently, as opportunity affords. (*E. A. Parkin, Mrs. P. J. Maycock, Miss D. G. Blackman.*)

OVER-WINTERING OF HOUSEFLIES

The Laboratory is collaborating with industry in an endeavour to find out whether it is possible for houseflies to over-winter as adults in buildings. A considerable number of premises are being held under observation, and samples of flies caught will be submitted, with full information, to the Laboratory for identification and sexing. At the same time experiments have been started at the Laboratory to investigate other ways in which flies can pass the winter, e.g. as larvae or pupae in manure or in the ground. The results of this investigation will have an important bearing on the design and application of control measures.

CONTROL OF BLOWFLIES IN SLAUGHTERHOUSES

The full-scale experiment at a large slaughterhouse, begun in 1948 and involving the routine dusting with 5 per cent DDT of refuse and nearby vegetation and the application of improved measures for hygiene, has continued. Infestations by adult flies were kept at a very low level and breeding on the premises almost entirely prevented.

It has become increasingly obvious that the infestation of slaughterhouses by blowflies presents two very distinct problems, (1) the prevention of breeding on the premises, and (2) the control of flies which breed in surrounding districts and are attracted to the slaughterhouse. Investigations have shown that blowflies breed freely in various industrial, shop, and domestic refuse, and that where such refuse is concentrated at a collecting and sorting depot vast numbers of the larvae migrate and adults emerge to re-infest the surrounding districts. It will be necessary to persist with chemical control measures against immigrating flies for as long as such breeding sites exist.

Laboratory studies on the migration of larvae were continued and it was shown that almost all migrate between 10 p.m. and 6 a.m. (G.M.T.), even though external temperatures are constant and the larval food is kept in darkness during the whole period of development and migration of larvae. In the course of one experiment, 75,802 larvae migrated from 45 lb. of slaughterhouse refuse (nearly 4,000,000 per ton); figures obtained previously were, therefore, well below the maximum for the population density in such refuse.

During the winter of 1949-50, samples of soil containing blowfly larvae were collected and it was confirmed that *Calliphora erythrocephala*, *C. vomitoria*, and *L. sericata* can overwinter in the ground as larvae which pupate and emerge in the spring. By trapping adults which emerged from the ground in the vicinity of refuse it was shown that in spring, 1950, *Calliphora* emerged in April, about one month earlier than *Lucilia*.

In laboratory experiments the rates of development have been determined for *P. terrae-novae*, *L. sericata*, and *C. erythrocephala* breeding in separate cultures at 24°C.

Full-scale control measures on an experimental basis were begun during 1950 at two further slaughterhouses but the cold, wet summer resulted in unnaturally low blowfly populations and assessment of results was difficult.

An attempt was made to enlist the co-operation of slaughterhouse staff to collect eggs so that the severity of the problem of the " blown " carcass could be assessed and related to species of fly, types of carcass, etc. ; full co-operation was not possible. An attempt will be made to complete the investigation with the help of meat inspectors of the Royal Sanitary Institute. (*A. A. Green, A. M. Simmonds, Miss M. J. Kane, Miss S. M. Nightingale.*)

TESTS OF PYRETHRUM STANDARDS AGAINST HOUSEFLIES

As reported last year, there was some indication that the commonly used standard pyrethrum solution was not completely reliable. Some solutions were prepared commercially for use as possible alternatives, and tests against houseflies have indicated that these solutions have not lost toxicity during 7 months storage at 20°C. (*A. A. Green, Miss M. J. Kane.*)

CONTROL OF HOUSEHOLD INSECTS

The policy has continued of carrying out *ad hoc* methods of control, whenever possible, with the object of gaining experience of the conditions under which infestations have to be dealt with.

Experiments with poison bait against the common black ant, *Acanthomyops niger*, have shown that the population can almost always be reduced to such a low level that the insects no longer cause a nuisance by foraging in the house. In many instances nests were depopulated by baiting but some were quickly recolonized, apparently by ants from other near-by nests. During 1950 some enquiries were dealt with by supplying bait, an instruction sheet, and a questionnaire which would provide useful information. Eight replies were received from 14 questionnaires; five recorded complete success, one partial success, and two failure. It is intended to carry out further tests where the failures occurred.

Experimental treatments of two heavy infestations of cockroaches were both successful. The first was a very heavy infestation, estimated to amount to several tens of thousands of the insects, in a pair of adjoining old cottages and involved the removal of harbourages such as skirting boards, mantel shelves, etc., the application of chemical control by sprays and dusts, and the carrying out of some minor structural alterations. The second infestation, which was less severe and more localized, involving about 6,000 to 8,000 cockroaches, was controlled by use of DDT and pyrethrum dusts.

Various inspections have been made and some treatments applied for clothes moths and carpet beetle infestations. Advice has been given by correspondence on control of ants, cockroaches, clothes moths, flies, silverfish, wasps, carpet beetles, and various other kinds of beetles. (*E. A. Parkin, A. A. Green, Miss M. J. Kane.*)

INSECT-PROOF PACKAGING MATERIALS

Investigations have continued on the development of cellulose wadding impregnated with DDT, which, as reported in the Annual Report for 1948, had been found in laboratory tests to be satisfactory as an insect-proof wrapping materials.

The method of application of the DDT during the process of manufacture has been studied in collaboration with a firm specializing in the production of

cellulose wadding. The wadding was impregnated by spraying the damp product with an aqueous suspension of DDT during the last stage of manufacture, i.e., just before a steam-heat drying stage. Analysis showed that the concentration of DDT attained was only 0·56 per cent by weight, as compared with the concentration of 1 per cent aimed at. Later experiments showed that this was probably due to evaporation of the insecticide in the steam during the drying process. (*T. A. Oxley, J. P. Heslop, E. A. Parkin.*)

EVALUATION OF NEW SYNTHETIC MATERIALS AS INSECTICIDES

The Director, Chemical Research Laboratory (D.S.I.R.) sent a further 25 samples for test as insecticides. These represented various fractions obtained after hydrogenation of alpha-picoline and hydrogenolysis of alpha-pipecoline at high temperature and high pressure. Two or three of the higher boiling fractions from the latter reaction had some insecticidal effect on the Granary Weevil, *Calandra granaria*, but not sufficient to suggest real promise.

The Laboratory has also continued to receive from Dr. S. H. Harper of King's College, London, samples of pyrethrin-like compounds which he has synthesized. Of the eight preparations tested against houseflies in the spray chamber, the four in which esterification had been carried out with the natural *d-trans*-chrysanthemic acid were more toxic than those formed from the synthetic *dl-trans*- or *dl-cis*-chrysanthemic acids. The toxicity of the molecule is, however, also greatly influenced by the structure of the unsaturated side-chain of the pyrethrolone residue.

Dr. Harper also supplied for test two lactones made from different isomers of chrysanthemic acid. One of these lactones was thought to be identical with a Japanese preparation for which definite toxic properties against flies were claimed. Tests as fly sprays of these compounds and of the chrysanthemic acids from which they were prepared have shown no useful insecticidal effect, but the method of test was quite different from the Japanese, in which much larger quantities of the compound per unit volume of space were applied by volatilization with heat.

A comparison has also been made between several samples of pellitorine, natural and synthetic. Pure and crude pellitorines prepared by Dr. Harper from ground pellitory root (*Anacyclus pyrethrum*) were about equally toxic as sprays against houseflies, but less than two-fifths as effective as pyrethrins. However, they were more potent than two isomers prepared from stillingia oil and one prepared completely synthetically, this last being virtually non-toxic. (*E. A. Parkin, A. A. Green, Miss M. J. Kane.*)

VARIATION IN INSECT RESISTANCE

A stock of the Flour Beetle, *Tribolium confusum*, has now been bred under carefully standardized conditions for several years and during the past year tests have been made at intervals to determine the stability of its resistance to methyl formate. The tests were made at weekly intervals for four months, and thereafter fortnightly: the series now amounts to 28 tests. In only one of the individual tests have the mortality data been heterogeneous in respect of their goodness to fit to the regression lines, but it is probable that the compounded data for the whole series will show heterogeneity. The variability of the slopes of the regression lines was within the limit of homogeneity for the first twenty-six experiments but became heterogeneous at the twenty-seventh. A small

transportable dust extraction apparatus has recently been constructed to enable the whole of the handling of cultures to be done in a constant temperature room, and tests will be made to ascertain whether this refinement of the breeding technique causes any appreciable reduction in the heterogeneity of results of successive tests.

The Laboratory has been aware for many years, from work with contact insecticides, that the resistance of beetles is altered by submitting them to the "shock" of handling shortly before treatment: a rest period of 16 to 20 hours is therefore always allowed for recovery of the normal level of resistance. This effect has been investigated in relation to the technique employed in this work on variability by separating the beetles from their food and counting them into batches at different periods before fumigation. The resistance of the beetles after rest periods of 1, 3, 6, 12, 24, and 48 hours was compared with that after the normal rest period of 20 hours. The regression lines for probit kill against log exposure-time showed significantly lower slopes for 1- and 3-hour than for 20-hour rest periods. Similarly, significantly shorter exposure times were required for equal mortality with rest periods of 1, 3 and 6 hours than of 20 hours, the results with the standard being more nearly approached as the length of the rest period increased. The results with rest periods of 12, 20, 24, and 48 hours showed no significant differences. In contrast to the remainder, the data for the 48-hour rest period were just heterogeneous, possibly an effect of starvation.

Experiments have also been made to investigate the effects of age and temperature on resistance of *T. confusum* beetles. Beetles which were 0-1 week old were too susceptible to give useful data, and the 1-2 weeks old group were intermediate between the very susceptible 0-1 week group and the more resistant and consistent, older groups. Beetles aged from 2-3 weeks to 11-12 weeks showed no marked differences in resistance, although there was a tendency for maximum resistance to be attained at 5-6 weeks. Increases in temperature caused the expected significant increases in kill over the range tested, viz., 20°, 25°, and 30°C. (*J. A. Hope*, *K. G. Gostick*.)

FUMIGANTS

As in 1949 the main work of the field team has been concerned with the fumigation of grain. The study of the behaviour of certain chlorohydrocarbons when applied to the surface of grain stored in bulk on floors has been continued. Experimental treatments of grain in silo bins with carbon tetrachloride produced unexpectedly satisfactory results, and following recommendations from the Laboratory, the method has been adopted by the Infestation Control Division of the Ministry of Agriculture and put into use on a large scale. The fumigation with methyl bromide of large stacks of bagged grain under gas-proof sheets has also been the subject of tests by the Laboratory.

Special investigations carried out at the request of other Departments have included a trial treatment of clothing with methyl bromide on behalf of the War Department, and trials of two methods of disinfesting dried fruits packed in sealed tins carried out for the Admiralty.

None of the developments in fumigation technique during the year have changed the view that the most reliable method of treating large bulks of grain is by fumigation in silo bins fitted for circulation of the gas. No further experi-

ence of this method has been gained during the year, but preliminary steps have been taken with a view to staging a further trial and demonstration in an existing silo of normal construction.

Studies of Fumigation Techniques

LOCALIZED FUMIGATIONS OF BULK GRAIN WITH CERTAIN CHLOROHYDROCARBONS

Further tests were carried out on the lines of those described in the Report for 1949, small selected areas of a large bulk of grain being treated by surface application of carbon tetrachloride and ethylene dichloride (1, 2-dichloroethane) either singly or admixed. The results have allowed the following general conclusions to be drawn:—

(a) Carbon tetrachloride, applied alone, penetrates rapidly into grain and it is not an efficient fumigant for the treatment of floor-stored bulk grain since low concentration-time products are obtained near the surface.

(b) Ethylene dichloride, on the other hand, when applied alone has poor powers of penetration into grain and is unsuitable for the treatment of any but very shallow bulks of two or three feet in depth.

(c) When mixtures of these two chlorohydrocarbons are used the downward penetration of ethylene dichloride is increased but there is a very marked separation of the two compounds as the depth increases. With warm grain, mixtures having volume ratios between 3 : 1 and 1 : 3 are all capable of giving reasonable distribution throughout a bulk of grain up to 15 feet in depth. On the whole, however, and especially when the grain is cool, a mixture of equal parts by volume appears to be most effective. It appears to be unneccessary to cover the grain surface after applying the fumigant, unless the air immediately above the surface is very warm (80°F. or more) when use should be made of a gas-proof sheet of the balloon or dinghy-fabric type.

(*H. K. Heseltine*, *S. G. Heuser*, *G. A. Hamilton*, *Miss B. D. Hole*, *J. B. Waller*.)

FUMIGATION OF GRAIN IN SILO BINS WITH CARBON TETRACHLORIDE

Reports from Canada indicated that grain could be treated effectively in silo bins with carbon tetrachloride applied during filling or to the grain surface in the filled bin. This last possibility was of particular interest since one of the disadvantages of treatments in bins with calcium cyanide (the method in current use in Britain) is the need to turn the grain from one bin into another for the purpose of applying the fumigant.

Trials were therefore conducted using gas-sampling methods to study the distribution of the carbon tetrachloride. Satisfactory distribution was obtained in a variety of bins ranging in depth from 50 to 116 feet by the simple method of spraying the fumigant evenly over the grain surface in the full bin. At temperatures above 60°F. a dose of 1 gallon of carbon tetrachloride to 12 tons of grain gave complete control in 7 days as judged by the gas-sampling results, the kill of test insects introduced into the grain at various depths, and, when the grain was infested, by the kill of insects in the grain. At temperatures below 60°F. downward penetration of the fumigant is slowed and the resistance of insects to it increases rapidly so that an effective treatment is probably impracticable in a 7-day period.

The fumigant is relatively safe and easy to handle in the open air or in well-ventilated spaces, but care must be taken to protect operatives against toxic

effects. It can be applied by watering can or by a hand or electric pump. No special sealing of the bin is required. At the end of the treatment the grain can be run off without risk to personnel working in the silo. While the process does not normally require the turning of the grain, any caking at or near the surface of the grain must be broken up and there is some evidence that when very steep temperature gradients are present (i.e. when " hot-spots " have been produced) turning may be advisable to ensure satisfactory distribution of fumigant. Milling and baking tests have been carried out by the Research Association of British Flour Millers on samples of wheat drawn from one of the bins treated with carbon tetrachloride and showed no deterioration in milling or baking quality and no taint in the bread. (*W. Burns Brown, H. K. Heseltine, S. G. Heuser, G. A. Hamilton, J. B. Waller.*)

FUMIGATION OF STACKS OF BAGGED GRAIN UNDER GAS-PROOF SHEETS

In the past two years the method of fumigating small stacks of commodities covered by a gas-proof sheet has been extended in this country to deal with much larger quantities. Thus it is not unusual to treat 1,000 tons of bagged grain in a single fumigation with methyl bromide. Initially, these very large treatments were carried out only for the eradication of mice, but chemical tests carried out by the Infestation Control Division of the Ministry of Agriculture, which was mainly responsible for these developments, showed that with some increase in the dose or time of exposure these fumigations could also be effective against insect pests. The Laboratory collaborated with the Division in two trials, the more important of which was designed to determine whether effective distribution of fumigant could still be obtained if the maximum width of stack were increased from 8 feet (as previously specified) to 12 feet. It is usual to treat a group of such stacks by covering with a series of large sheets of proofed fabric (e.g. dinghy fabric), the edges of sheets being rolled together to make tight joins. Outside the group of stacks the sheets are weighted down to the floor with chains. The methyl bromide is introduced through fine jets into the alleyways between stacks. Gas sampling methods showed that distribution of methyl bromide throughout the 12 feet wide stacks was remarkably good. Fumigant quickly reached the centre of stacks and losses by leakage appeared to be small. (*H. K. Heseltine, G. A. Hamilton, J. B. Waller.*)

FUMIGATION OF CLOTHING INFESTED BY ANTHRENUS VORAX

During 1949 the War Department sought the advice of the Laboratory on the control of *Anthrenus vorax* (" Woolly Bear ") found infesting compressed bales of great-coats and other clothing returned to this country from stores in the Far East. It was considered that fumigation with methyl bromide offered the best chance of successful control. Advice was given on the selection and adaptation of a building as a fumigation chamber and on the method of exposing the clothing to the fumigant. A trial fumigation was carried out and gas sampling methods showed that distribution of fumigant was satisfactory. Cages each containing 50 larvae of *A. vorax* were inserted between folds of clothing at selected points before the start of the treatment. Of the 450 insects exposed there were only two survivors. It was concluded that with some increase in the dose used in the trial the method could be expected to give a satisfactory measure of control. (*W. Burns Brown, H. K. Heseltine, Miss E. M. Reynolds.*)

FUMIGATION OF DRIED FRUITS IN TINS

Various dried fruits are packed by the Admiralty in tins which are sealed by soldering before despatch to depots overseas. The Laboratory was asked to advise on a simple method of disinfesting the fruit in the tins at the time of packing. The problem was one of general interest and the Laboratory undertook to test two methods which appeared to satisfy the requirements of ease and safety of application: (a) a large proportion of the air in the tin was replaced by carbon dioxide drawn as gas from a cylinder and introduced by means of a hollow spear thrust down to the bottom of the tin; (b) a small measured dose of ethylene dichloride was introduced.

The tests were made on tins each containing 30 lb. of currants. The insects used were *Plodia interpunctella* (larvae and pupae), *Ephestia cautella* (larvae and pupae), and *Oryzaephilus surinamensis* (all immature stages.) The treated tins were kept for 30 days at 25°C. before being opened and examined. Complete control was given under the conditions of these preliminary tests by the mildest treatments, i.e. a dose of carbon dioxide (applied in 5 seconds), giving a mean concentration of between 20 and 25 per cent by volume, or a dose of 1 ml. of ethylene dichloride, per tin. The tests confirmed the practicability of both methods, though additional tests will be necessary to establish the minimum treatments under different conditions. (*W. Burns Brown*, *Miss M. F. East*.)

Toxicity of Fumigants to Insects

It had been expected that during 1950 additional apparatus for studying the toxicity of fumigants to insects would be brought into use. The specially designed fumigation chambers were completed and erected during the summer but there have been considerable delays in completing the air-conditioning plant which will serve the two rooms in which the chambers are installed, and, up to the end of the year, full tests on the equipment have not been possible. The expansion in the scale of testing which the new equipment will allow has necessitated planning and preparing for the breeding and handling of larger numbers of insects. In addition, an increased amount of time has been given to the statistical examination of data already collected. As a result, during the year experimental work has been on a reduced scale.

TESTS WITH METHYL BROMIDE

Further data have been obtained on the resistance of *Trogoderma granarium* larvae to methyl bromide. These larvae are exceptionally resistant to starvation and to adverse physical conditions, a characteristic which, for a number of species, appears to be correlated with resistance to methyl bromide. The dose required for 100 per cent kill of these larvae is high by comparison with other species, but the difference is less marked at the level of 50 per cent kill. For example, at 25°C. the dose required to give 100 per cent kill of *T. granarium* larvae is about twice that required for adults of *Tribolium confusum*, whereas for 50 per cent kill the doses are similar. In other words the higher dose required at 25°C. for 100 per cent kill of *T. granarium* is due to greater variation between individuals rather than a higher general level of resistance.

T. granarium larvae exhibit thigmokinesis to a marked degree, and when this results in inhibition of movement the resistance to methyl bromide is increased.

This characteristic is probably of considerable importance in the application of control measures, and it can cause variation of mortality between samples in laboratory tests unless great care is taken to avoid its effects. The design of the cages in which the larvae are exposed for test is of prime importance. A change from wire gauze cages closed by muslin covered cotton wool plugs to machine-made cages closed by tightly fitting metal caps had been shown to have no effect on the mortality of adults of *T. confusum* or *Calandra granaria* exposed to methyl bromide, whereas with larvae of *T. granarium* consistently lower mortalities were obtained in the first type of cage in which the larvae tended to squeeze into the groove between the plug and the metal gauze.

In a continuation of tests on the effects of post-fumigation treatment it has been found that *T. confusum* adults fumigated at 15°C. and taken immediately to 25°C. survived to a much greater extent than those kept at 15°C. If taken to 33°C. instead of 25°C. this effect was less marked. *C. granaria* adults tested in the same way showed no such differences in mortality. (*Miss E. M. Reynolds, Miss B. D. Hole, I. McCalla, Miss M. F. East.*)

TESTS WITH CHLOROHYDROCARBONS

In connection with the field trials of carbon tetrachloride and ethylene dichloride as fumigants for treating bulks of grain, a few preliminary toxicity tests were carried out under conditions similar to those being experienced in the field, including temperatures below 10°C. About 130 lb. of wheat was treated in a gas-tight steel drum which could be rotated to ensure thorough mixing. Cages containing adults of *Calandra granaria* were then inserted in the grain and exposed for periods of 2 to 10 days. Concentrations of each chlorohydrocarbon were measured chemically at intervals throughout each test. After exposure the insects were kept at 15°C. and at this temperature they continued to die over a considerable period after the end of the exposure so that the concentration-time (c.t.) product necessary to produce 100 per cent kill depended on the period at which the mortality was assessed. For example, in a test in which a 3 : 1 mixture by volume of ethylene dichloride and carbon tetrachloride was used and the temperature varied between 7 and 10°C. the c.t. products (in mg. hr. per litre) of the two components required to give 100 per cent kill at different periods after exposure were as follows :—

Period after exposure at which 100 per cent kill was obtained	c.t. products $C_2H_4Cl_2$	c.t. products CCl_4
0 days	4100	2750
24 ,, ...	2400	1600
38 ,, ...	1850	1200
52 ,, ...	1850	1200

Using carbon tetrachloride alone in a test in the same temperature range a c.t. product of about 18,500 was required to give 100 per cent kill 12 days after exposure. (*Miss E. M. Reynolds, Miss B. D. Hole, G. A. Hamilton, Miss F. M. East.*)

BIOCHEMISTRY

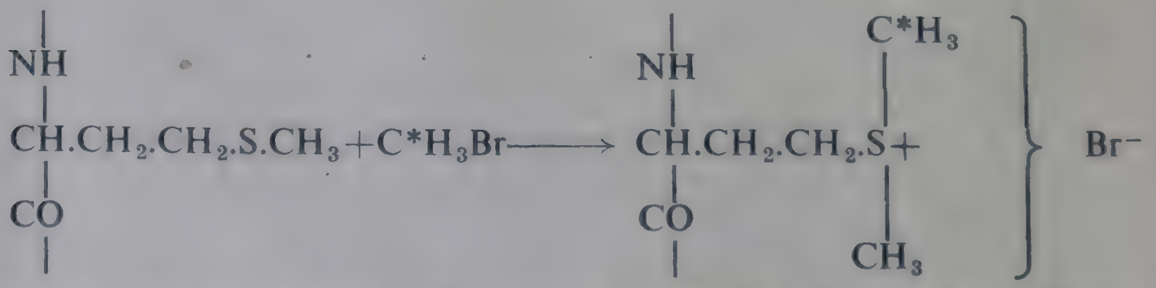
Insecticide Biochemistry in Relation to Foodstuffs

METHYL BROMIDE RESIDUES IN WHEAT

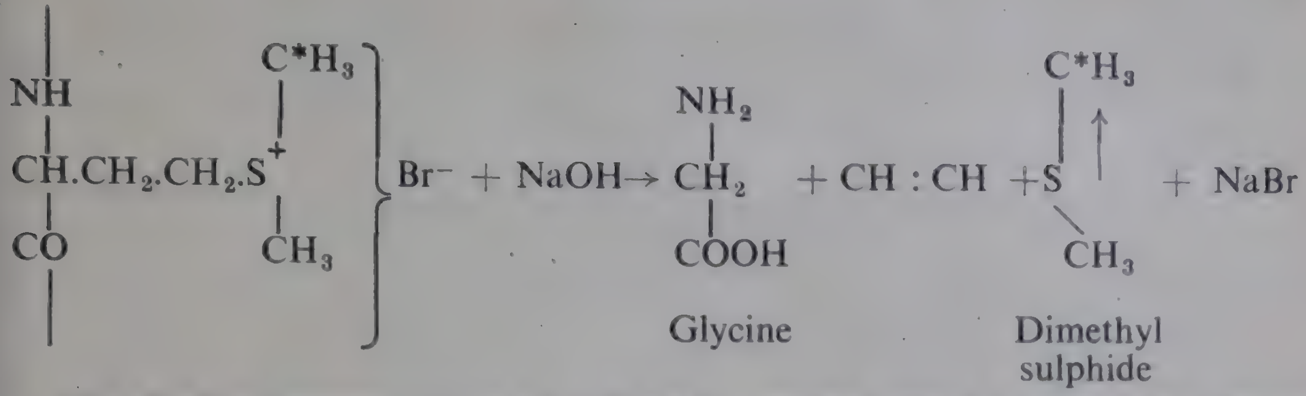
Previous work at this Laboratory and elsewhere has shown that when methyl bromide is used for fumigating wheat, some of the fumigant combines chemically with the wheat, and with the protein constituents in particular. During this reaction the bromine of the methyl bromide is liberated as water-soluble bromide. The increase in the water-soluble bromide content of the wheat, which is readily determined analytically, has thus been used as an index of the magnitude of the combined fumigant residue. The bromide content alone however gives no information about the more important methyl group.

An important amino acid of wheat protein is methionine. Methyl bromide combines with this acid with the formation of methyl methionine sulphonium bromide. The reduction in the methionine content of purified proteins on exposure to methyl bromide has been demonstrated. This sulphonium salt tends to decompose, especially under alkaline conditions, with the liberation of the unpleasantly smelling dimethyl sulphide. Qualitatively the spontaneous decomposition appears to account for the taint observed in wheat and flour exposed to heavy concentrations of the fumigant. The next problem was to determine to what extent methyl bromide combined with methionine, as well as with other protein groups of the wheat, under the conditions of fumigation. The relatively low concentrations of fumigant involved made investigation of the problem by conventional analytical methods impracticable. Milled wheat was therefore exposed to methyl bromide labelled with radioactive carbon–14. By treating the exposed wheat or its chemical fractions with different reagents it was possible to get a quantitative picture of the major reactions involved.

Samples of the starch, fat, gluten (wheat protein) and water-soluble constituents were obtained by fractional extraction of the milled wheat which had been aerated following exposure to the labelled fumigant. The total radioactive carbon content of these samples was assayed to indicate the relative extents to which the constituents had reacted chemically with the methyl bromide. The subsequent analysis was based on the following principles: The reaction of labelled methyl bromide (an asterisk denotes radioactive carbon atoms) with the methionine of wheat protein proceeds as follows:—



On treatment with alkali the protein sulphonium salt probably decomposes as follows:—



The alkaline decomposition of —$S.C^*H_3$ groups formed by the methylation of protein thiol groups (e.g. cysteine) can be represented as follows:—

$-S.C^*H_3 + NaOH \longrightarrow C^*H_3NaS + -OH.$

On adding acid:—

$C^*H_3NaS + HCl \longrightarrow C^*H_3.SH\uparrow + NaCl$
Methyl mercaptan

The $-S.CH_3$ group of unchanged methionine also yields methyl mercaptan but the volatile mercaptan would not then contain radio-active carbon. The volatile dimethyl sulphide resulting from any sulphonium salt and the mercaptan resulting from any methylated thiol groups can be isolated as the mercuric chloride and mercuric cyanide derivatives respectively. The radioactive carbon found in these derivatives is therefore a direct measure of the sulphonium and methyl thiol compounds formed in the wheat by exposure to the labelled methyl bromide. Methoxy groups —$O.C^*H_3$ may also be formed on exposing wheat to methyl bromide, e.g., by the esterification of free carboxylic acid groups of glutamic acid. These groups, as well as the sulphur derivatives, all yield volatile methyl iodide on mild hydrolysis with hydriodic acid. The radioactive carbon content of the methyl iodide obtained in this manner is therefore a direct measure of the three groups: —$O.C^*H_3$, $S.C^*H_3$, and $CH_3.S.C^*H_3$. The difference between the radioactive carbon determined in the methyl iodide and in the volatile sulphur compounds is therefore an indirect measure of the —$O.C^*H_3$ groups formed in the wheat. Drastic treatment of the wheat protein with hydriodic acid in the presence of ammonium iodide decomposes $>N.CH_3$ groups with the formation of methyl iodide so that the radioactive carbon content is now a direct measure of the formation of these groups in the exposed wheat.

Experiments on the foregoing lines were made in the presence of suitable unlabelled "carrier" substances so that the small quantities of labelled volatile products could be handled by ordinary chemical techniques. It was found that in wheat containing 14 per cent moisture and a combined methyl bromide residue corresponding to 515 p.p.m. bromide the methyl groups were distributed as follows:—

Gluten fraction	87·0%
Starch fraction	9·6%
Water-soluble volatile fraction	2·9%
Ether-soluble fraction	0·5%
	100·0%

Any free methyl alcohol directly formed by fumigation must be less than the 2·9 per cent found in the water soluble volatile fraction since this fraction almost

certainly contained traces of decomposition products and possibly a trace of unchanged methyl bromide.

The following types of compounds were found roughly to account for the total residue of the gluten fraction:—

Methyl sulphonium derivatives ..	$-\overset{+}{S}\langle^{C^*H_3}_{CH_3}$	..	35·4%
Thiomethoxy derivatives	$-S.C^*H_3$	..	7·0%
Methylated nitrogen derivatives ..	$>N.C^*H_3$	..	41·6%
Methoxy derivatives	$-O.C^*H_3$	..	16·0% (by difference)

Two compounds containing sulphur of the type believed to be formed in significant proportions in the fumigated wheat have been prepared in the Laboratory. These are methyl methionine sulphonium bromide and S— methylcysteine; arrangements are being made for tests of their possible mammalian toxicity. Work on the identity of compounds containing the $>N.C^*H_3$ group is in progress. Further toxicity tests will be arranged unless the identified compounds are known to be innocuous. (*F. P. Winteringham, S. E. Lewis, A. Harrison, R. G. Bridges.*)

Work reported earlier has indicated that when DDT is sprayed on to wheat grains about one-quarter of the residual insecticide finds its way into the flour by milling at 85 per cent extraction. Evidence was obtained that during subsequent bread-baking part of a DDT residue would be decomposed. The nature of this decomposition has been investigated by the chromatographic analysis of a residue of a radioactive bromine analogue of DDT in flour. The suspected decomposition has been confirmed and takes place almost entirely within the crust of the loaf during baking. In the crust more than half of the residual DDT becomes decomposed with the formation of what seems likely to be the corresponding benzophenone derivative. A small fraction of the DDT loses hydrochloric acid with the formation of the ethylene derivative. Work proceeding will establish the identity of the principal decomposition product and it will then be determined if its mammalian toxicity is greater or less than unchanged DDT. (*F. P. W. Winteringham, A. Harrison, R. G. Bridges.*)

RESIDUES OF OTHER INSECTICIDES

Preparations are well advanced for studying residual ethylene oxide and residual benzene hexachloride in foodstuffs on the lines of the work so far reported. (*F. P. W. Winteringham, A. Harrison.*)

Insecticide Biochemistry in Relation to Insects

INHIBITION OF CYTOCHROME OXIDASE IN INSECTS BY FUMIGANTS

In the Annual Report for 1949 work on the location of thiol groups in insect tissue, and on their suppression *in vivo* in insects exposed to various fumigants, was described. Similar tests have now been made on the distribution of the respiratory enzyme cytochrome oxidase and its inhibition *in vivo* by exposing the insects to various fumigants. The enzyme was identified histochemically in frozen sections prepared from live and poisoned blowfly larvae as the oxidase, which was specifically inhibited by sodium azide and which gave a positive " Nadi " reaction within a given range of P_H values. The enzyme was found

be widely distributed in the insect tissue. Of the ranges of fumigants tested e Annual Report for 1949) only hydrogen cyanide was shown conclusively nhibit this particular enzyme as well as other oxidases. (*Miss P. M. Loveday.*)

TION OF SOME INSECTICIDES ON CHOLINESTERASE

The action of cholinesterase is to hydrolyze acetylcholine, and it is intimately nnected with the transmission of nerve impulses across ganglionic synapses d at neuromuscular junctions. It has been suggested that cholinesterase is e of the many enzymes requiring the presence of one or more " SH " groups the protein portion of the molecule. Earlier work had demonstrated that thyl bromide was a powerful inhibitor of SH enzymes; it was therefore of erest to study the effect of this and other fumigants on cholinesterase pre-rations.

An active cholinesterase preparation was isolated from washed ox-blood throcytes. The activity of the preparation was measured manometrically the Warburg method at 37°C. The specificity of the preparation was checked using benzoylcholine as substrate. No hydrolysis was observed, and it was sumed that the preparation was a " true " cholinesterase.

The enzyme in 0·15M bicarbonate solution was exposed to the insecticide all-glass flasks for one hour at 37°C. The insecticide was then removed, her by a stream of nitrogen, or by precipitation of the enzyme and resus-nding in fresh solution. The activity of the treated and control samples s then determined. The insecticides tested included methyl bromide, carbon ulphide, chloropicrin, and trichloracetonitrile. Of these, trichloracetonitrile s the only substance which produced any inhibition at a concentration in air 355 mg/l. At this concentration it produced 70 per cent inhibition. At a ncentration of 187 mg/l, 50 per cent inhibition was produced.

Trichloracetonitrile breaks down in aqueous solution in the following nner:—

$$CCl_3.\,CN + 2H_2O \longrightarrow CCl_3.\,COOH + NH_3.$$

sample of cholinesterase was therefore treated with a solution of CCl_3. OOH and NH_3 equivalent to a concentration of 187 mg/l CCl_3. CN_3 but no ibition was produced. It appears therefore that the inhibition is produced the intact molecule and not by the decomposition products.

Further tests will be carried out on the cholinestrase activity of the nerve cord the cockroach (*Periplaneta americana*) from which an active preparation has eady been obtained. (*S. E. Lewis, Miss B. G. Halls.*)

E OF YEAST TO DETERMINE THE ACTION OF SOME INSECTICIDES ON CELLULAR METABOLISM

Work has been started to obtain some information on the action of methyl omide and other insecticides on cellular metabolism.

A culture of *Saccharomyces cerevisiae* is being maintained to study the effect insecticides on cell division, viability, and metabolism.

Preliminary tests with methyl bromide indicate that some inhibition of cell vision is produced at a concentration as low as 8×10^{-5}M. (*S. E. Lewis, iss B. G. Halls.*)

APPENDIX I

Pest Infestation Research Publications

(*a*) *Papers Published in* 1950

1. Brown, W. B. Fumigants for Insect Control in Stored Foodstu *World Crops*, 1950, **2** (6), 241–244.
2. Herford, G. V. B. Some Research Problems in the Field of Stor Products Entomology. *Proc.* 8. *int. Congr. Ent. Stockholm, 194* 1950, 826–829.
3. Hewlett, P. S. & Plackett, R. L. Statistical Aspects of the Independe Joint Action of Poisons, particularly Insecticides. II. Examinati of the Data for Agreement with the Hypothesis. *Ann. appl. Biol.*, 19 **37** (3), 527–552.
4. Howe, R. W. The Development of *Rhizopertha dominica* F. (C Bostrichidae) under Constant Conditions. *Ent. mon. Mag.*, 1950, (1028), 1–5.
5. Howe, R. W. Studies on Beetles of the Family Ptinidae. III. A Tw Year Study of the Distribution and Abundance of *Ptinus tectus* Boie in a Warehouse. *Bull. ent. Res.*, 1950, **41** (2), 371–394.
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b) Lectures and Broadcast Talks

The DIRECTOR: "Some Research Problems in Stored Products Infestation" (Royal Sanitary Institute).

"The Physics of Bulk Grain Storage" (Ministry of Agriculture and Fisheries Conferences on grain storage, held at Chelmsford and Canterbury).

"Pest Infestation in the Middle East" (B.B.C. Arabic Service).

E. A. PARKIN: "Biological Tests of Insecticides for Stored Product Insects." (Crop Protection Panel of the Agriculture Group, Society of Chemical Industry).

T. A. OXLEY: "Some Difficulties of Grain Storage" (A.G.M. Conference of W.H.D. Seed Growers).

Six lectures on Grain Storage, in a "commodity" course given at the City of London College.

Broadcast discussion on grain storage in "Calling East Africa."

W. BURNS BROWN: "Factors affecting the Distribution of Fumigants." (London and S.E. Section of the Royal Institute of Chemistry).

F. P. W. WINTERINGHAM: "Radiometric Assay in Tracer Research" (Physical Methods Group of the Society of Public Analysts).

Miss M. B. HYDE: "The Occurrence and Significance of Sub-epidermal Fungi in Cereal Grains." (7th International Congress of Botany, Stockholm).

A. A. GREEN: "Blowflies in Slaughterhouses." (Royal Sanitary Institute).

G. E. WOODROFFE: "Birds' Nests as a Source of Domestic Pests." (Zoological Society).

APPENDIX II

Staff of the Pest Infestation Laboratory
1950

Director of Pest Infestation Research—G. V. B. Herford, O.B.E., M.Sc.
Senior Principal Scientific Officer—E. A. Parkin, Ph.D., M.Sc., D.I.C.
Principal Scientific Officers—T. A. Oxley, B.Sc., A.R.C.S.; W. B. Brown, M.Sc., F.R.I.C., A.R.C.S., D.I.C.; M. E. Solomon, M.Sc.
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Senior Experimental Officer—A. A. Green.
Experimental Officers—A. M. Cunnington; K. S. Fowler, B.Sc.; A. Harrison; H. K. Heseltine, B.Sc.; S. G. Heuser; Miss H. C. N. Turnbull, M.A.
Assistant Experimental Officers—G. Ayerst; R. G. Bridges; H. D. Burges; *W. T. Dundas, B.Sc.; Miss B. Edwardes-Evans, B.A.; Miss W. M. Eustace; G. A. Hamilton; Miss B. G. Halls; J. P. Heslop; Miss B. D. Hole; Miss J. R. Long; Miss P. M. Loveday, B.Sc.; *I. McCalla; Miss S. G. Rawle, B.Sc.; Miss P. L. Robertson, M.Sc.; Miss G. M. Skellon, B.Sc.; *Mrs. E. M. D. Smith; A. M. Simmonds; Miss M. K. Winckler; G. E. Woodroffe.
Senior Assistants (Scientific)—A. E. Broughton; Miss E. M. Reynolds.
Assistants (Scientific)—Miss B. E. Adamson; Miss D. G. Blackman; *Mrs. J. M. Bond; D. Budd; Miss B. Clayton; Miss J. E. Currie; Miss M. F. East; K. G. Gostick; *Miss E. M. Greet; *Mrs. U. E. Harding; G. C. Hellyer; Miss M. J. Kane; Miss E. A. Myerscough; Miss S. M. Nightingale; B. J. Southgate; K. I. Street; J. B. Waller; Miss S. R. Wiley.
Senior Photographer—J. H. Hammond, A.R.P.S.
Assistant Photographer—Miss A. M. Stott.
Clerical Officers—H. W. Cooke; T. F. Morgan; Miss M. M. Wood.
Temporary Clerks and Typists—*Mrs. M. N. Dales; *Miss R. How; Miss M. L. Shenton; Mrs. P. Horwood; Miss L. E. Ranscombe.
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Cleaners—*Mrs. A. Clements; Mrs. E. A. Day; *Mrs. V. Ward; Mrs. M. Waters; Mrs. M. Williams.
Gardeners—*A. Jackson; A. O. Moss; L. Thomas.

* Resigned in 1950.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

REPORT OF THE PEST INFESTATION RESEARCH BOARD

WITH THE REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH

FOR THE YEAR 1951

LONDON: HER MAJESTY'S STATIONERY OFFICE
1952

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31st December, 1951

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Department of Scientific and Industrial Research,
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REPORT OF THE PEST INFESTATION RESEARCH BOARD FOR THE YEAR 1951

To the Lords of the Committee of the Privy Council for Scientific and Industrial Research

MAY IT PLEASE YOUR LORDSHIPS,

WE, the Pest Infestation Research Board, beg leave to present a report on our proceedings during the year 1951. The Report of the Director of Pest Infestation Research for the same period is appended.

RESEARCH PROGRAMME

We consider that good progress has been made during the period under review.

From a wide field of activity, the following are some examples of work now in progress.

RESIDUAL POPULATIONS OF INSECTS IN FOOD STORES

Many old warehouses contain, in cracks in walls, floors etc. quantities of spilled foodstuff sufficient to support an appreciable population of insect pests. Little is known of the size or significance of such residual insect populations, and the opportunity has therefore been taken to examine in detail the deposits of infested foodstuff contained in the fabric of warehouses in process of being demolished.

In one such building, containing many double wood-framed partition walls, considerable deposits of infested grain were found, supporting very large populations of the common warehouse pests.

Another warehouse, built with solid brick walls throughout, supported only a very sparse fauna.

Apart from the practical significance of this work linking type of construction with liability to infestation, it is hoped that some interesting studies may be made of the biological interactions within such insect populations, when the amount of foodstuff is limited.

CONTROL OF BLOWFLIES

Work on the control of blowflies in slaughterhouses has continued, and although considerable success has been achieved by local treatment, it is clear that complete control can only be ensured by eliminating other fly-breeding grounds in the neighbourhood. One such source of major infestation was a large refuse-collecting and sorting depot near a slaughterhouse. During the past summer extensive trials with different insecticidal formulations have been carried out at this depot, and it is expected that as a result of this work it may be possible to reduce the blowfly infestation in such places to a negligible level.

BIRDS' NESTS AS A SOURCE OF PESTS

As mentioned in our Report for 1950, a survey has been made during the last eighteen months of the insect fauna of disused birds' nests taken from

houses and other buildings. More than 200 nests have now been examined. It has been shown that the insect and mite fauna of a dry birds' nest corresponds very closely with that of a neglected food warehouse.

It is also significant that larvae of certain clothes moths and carpet beetles are found frequently in large numbers in these nests, which are quite possibly acting as invasion centres for the infestation of houses.

TOXICITY OF FUMIGANTS TO INSECTS

The provision of two cool air-conditioned rooms each equipped with a fumigation chamber has made possible a great expansion in the work on the toxicity of fumigants to insects at relatively low temperatures.

Experiments with certain chlorinated hydrocarbons have shown that when insects are fumigated at 10° or 15°C. and subsequently kept at that temperature, as would usually be the case in practice, the percentage mortality increases over a long period and the dose necessary for a final complete kill is correspondingly decreased.

ACTION OF INSECTICIDES ON CELLULAR METABOLISM

A decrease in the rate of phosphorylation of glucose by dried yeast which had been treated with methyl bromide suggested the inhibition of the enzyme hexokinase. Further evidence of such inhibition has been obtained by using radioactive phosphate to study the formation of phosphate esters during the utilization of glucose by a cell-free extract. Using paper chromatography it has been possible to show that treatment with methyl bromide causes a reduction in phosphate uptake and in the formation of glucose-6-phosphate and fructose-1:6-diphosphate.

OVERSEAS LIAISON

We are glad to learn of the appointment of Mr. D. W. Hall, as Colonial Liaison Officer to the Laboratory. Mr. Hall will be making his first tour, to East Africa, early in 1952. It is encouraging to note that there has already been a marked increase in the number of enquiries from the colonies since the announcement of Mr. Hall's appointment.

We congratulate Mr. F. P. W. Winteringham on the award of a Commonwealth Fund Fellowship. He is now working with Professor Hoskins in the University of California on the mode of action of insecticides.

Mr. T. A. Oxley, who was awarded a Nuffield Foundation Travelling Fellowship in 1950, was in Australia and New Zealand until July 1951, studying methods of storing and handling grain, and related research work.

On his return Mr. Oxley spent two weeks in Cyprus advising the Government at their request, on matters of grain storage.

At the request of the British Council, the Director spent three weeks in Portugal, lecturing on infestation problems, visiting scientific institutions and examining food storage conditions throughout the country as a whole.

Dr. Parkin and Mr. Solomon attended the IX International Congress of Entomology in Amsterdam. Two papers were read by Dr. Parkin and one by Mr. Solomon, dealing respectively with the use of insecticidal smokes for the control of insects in granaries, the control of blowflies, and the population dynamics of storage pests. After the Congress visits were paid to entomological institutions in the Netherlands (Wageningen, Osterbeek, Deventer,

elgium (Brussels, Liege), Switzerland (Basle, St. Gallen), and France (Paris). Mr. Burns Brown and Mr. Heseltine spent a week in Switzerland examining nstallations for fumigating grain in silo bins by gas circulation.

As mentioned in previous reports, work at the Laboratory has clearly demon-trated the efficiency achieved by using a gas circulation technique for the umigation of grain in silo bins. In view of the potential importance of this nethod, every opportunity was taken to obtain technical information, photo-raphs, etc. of the different Swiss installations. On the return journey three ays were spent in France inspecting vacuum fumigation installations.

During the year under review the Laboratory received visitors from the ollowing countries; Australia, Belgium, British Guiana, Canada, Cyprus, Denmark, Egypt, France, Germany, India, Lebanon, Mauritius, New Zealand, Nigeria, Nyasaland, Pakistan, St. Helena, Switzerland, Tanganyika and the Jnited States of America.

LIAISON WITH OTHER DEPARTMENTS

MINISTRY OF AGRICULTURE AND FISHERIES

The infestation Control Division of the Ministry of Agriculture and Fisheries s still the main channel through which the results of research in the Labora-ory may be directed into practice and it is therefore in the interests of both organizations to foster close contacts between staff at all levels and, wherever possible, to promote collaborative field experiments.

We are glad to know that excellent relations are maintained between the Laboratory and the Infestation Control Division.

COLONIAL OFFICE

The Director has recently been appointed Chairman of the Stored Products Research Sub-Committee of the Colonial Office, in succession to Sir John Simonsen, whose term of office had expired.

Contact between the Laboratory and the Colonial Office will be further strengthened by the appointment of the Colonial Liaison Officer, mentioned above.

OTHER ACTIVITIES

During the year, help by advice or discussion has been given on a variety of problems to the War Office, Admiralty, Ministry of Supply, Ministry of Food, Ministry of Health, Ministry of Transport, Agricultural Research Council, Overseas Food Corporation, National Coal Board, Royal Sanitary Institute and many local authorities.

Short instructional courses have been given during 1951 to a group of eight Army Officers and to two groups of West African Produce Inspectors.

Twenty-two papers have been published and fifteen lectures delivered in the course of the year.

March, 1952.

J. L. SIMONSEN,
Chairman

REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH FOR THE YEAR 1951

BIOLOGY

The work of the Biology Section in 1951 has included two new developments in field work. One of these is a study of the populations of pests and associated species living in the recesses of storage buildings; the other is a series of weekly observations of the grain beetle *Oryzaephilus surinamensis* in a warehouse. Life history work, i.e., the study of rates of development, survival and reproduction under various conditions of temperature and humidity, has been extended to two additional species of mites and two well-known beetle pests especially important in West Africa, *Trogoderma granarium* and *Tribolium castaneum*. Otherwise, staff have been fully occupied in developing projects begun in previous years.

Towards the end of the year, Miss P. L. Robertson left to work for a higher degree at Cambridge, where she will continue her investigations on cheese mites.

DISTRIBUTION AND IMPORTATION OF INSECTS

By courtesy of the Infestation Control Division of the Ministry of Agriculture and Fisheries, the summarizing of their records of inspections of cargoes from West Africa has continued. The inspectors of the Division have also co-operated in investigations of the status of the grain beetles *Laemophloeus* and *Oryzaephilus*, by submitting specimens taken from numerous infestations.

In the infestations of West African produce, the most important changes since the previous year have been, firstly, a considerable reduction in the numbers of the Khapra Beetle, *Trogoderma granarium*, following poor groundnut crops in two successive years, with consequent shortening of the storage period in West Africa; and, secondly, an increase in the proportion of cargoes of cocoa beans infested by the Cigarette Beetle, *Lasioderma serricorne*. The other typical West African species continue to appear without change in status.

From the identification of specimens of *Laemophloeus* the most important points that arise are as follows: (1) *L. turcicus* is almost exclusively the species found in flour mill machinery, and since it is seldom found on produce elsewhere, it must be concluded that this species survives the periodic fumigations of flour mills, or finds its way back to mills from infested bakeries. (2) A new species, of which a scientific description is being published, has been imported almost solely from Brazil and Australia, and is frequently associated with Brazilian rice. (3) *L. ferrugineus*, a native British species, is still the only one established in unheated premises away from the ports. (4) *L. ferrugineus* and *L. minutus* appear to be of world wide occurence.

Of the two species of *Oryzaephilus O. mercator* has come almost entirely from tropical countries, and *O. surinamensis* almost entirely from temperate areas. Both species have been imported from Argentina, Brazil, and Uruguay. This picture may, however, reflect only the character of the cargoes imported, for *O. surinamensis* has been shown to thrive in tropical conditions. Analysis of imports has shown that *O. mercator* is the species found in oilseeds (i.e. tropical

and S. American exports) and *O. surinamensis* the species found on cereals and starchy substances (i.e. temperate and S. American exports). (*R. W. Howe*).

RESIDUAL POPULATIONS IN STORAGE BUILDINGS

After removal of stores from a warehouse small amounts of the commodity usually remain in the building, providing food for insects. This residual food may be in cracks in the walls and floors, or, as with cavity walls and double floors, may penetrate more deeply into the fabric of the building. Insects living in this food are often protected from insecticides and fumigants and form foci for the infestation of goods stored later.

Little is known of the amounts of material or numbers of insects in these protected spots, and field observations are being made whenever demolition or building repairs permit observation and sampling. Two such investigations have already been completed. The first was at a small, single-storey warehouse with solid brick walls and concrete slab floor. It stood on the banks of a river; drainage was bad, and as a result the floor was very damp. A few *Endrosis lactella* and *Ephestia elutella* were found on the walls, but the main constituents of the sparse fauna comprised damp-loving forms (fungus beetles, mites, Psocids) and cellar-dwelling beetles [*Rhyzophagus* (Colydiidae), *Xylodromus* (Staphylinidae)]. There were few cavities and no residual food was found.

The second was at a large five-storey granary with cavity walls containing large deposits of grain and many insects. Some of the insects could be directly connected with the type of storage, but others were more general warehouse pests. The most abundant species were *Hofmannophila pseudospretella*, *Tenebrio molitor*, *Calandra granaria* and *Ephestia elutella*. Other insects found included many of the common pests, as well as Hymenopterous parasites, Hemiptera, *Scenopinus* (Diptera) and predaceous mites.

The numbers of living insects found in various sample areas were high. The photograph (Plate I(A)) shows a cavity, revealed by removal of the inner wall, in which there were over 7,000 *Hofmannophila* larvae. In another such area there were over 2,000 adult *Calandra granaria* and in each of three others, 1,000 *Tenebrio* larvae.

These two buildings probably represent extremes in the range of residual infestation, but as more observations are made a general picture should be formed. When this has been achieved the most prominent problems will be studied experimentally in the laboratory to increase our knowledge of the biological interactions within the populations. (*C. W. Coombs*).

OVERWINTERING OF STORAGE PESTS

As explained in last year's Report, cultures of many species of insects have been exposed to winter conditions in several types of situation, ranging from a fairly well protected site in an unheated building to an outdoor screen. The object is to collect more information about the overwintering powers of different species. The results to date are being studied, and another set of cultures has been put out for the winter of 1951–2. (*M. E. Solomon, Miss B. E. Adamson*).

OBSERVATIONS ON *Oryzaephilus surinamensis* IN A WAREHOUSE

A warehouse containing a large population of the Saw-toothed Grain Beetle has been observed weekly for a year. The building is old and the fabric pro-

vides many suitable niches in which storage insects can breed undisturbed. Bulk grain is stored and the turnover is rapid, a factor which has hindered the build-up of a large population and has also made it impossible to conduct a series of consecutive observations under similar conditions. Generally very few *Oryzaephilus* were seen on grain, and not many were observed on bulk-heads. Occasionally, however, very large numbers (about 1,500/sq. ft.) were found. These congregated, for example, in spring and summer on small areas of floor exposed to full sunlight and having a local temperature of about 30 °C., i.e. more than 10° above the air temperature. Large numbers were also found on walls surrounding maize which was heating as a result of infestation by *Ephestia elutella*. Many *Oryzaephilus* were killed on surfaces sprayed with pyrethrum in oil for the control of migrating *Ephestia* larvae.

The temperature in the warehouse rarely rose above 20 °C. which is about the developmental minimum of *Oryzaephilus surinamensis*, and it is tentatively concluded that the outbreaks of this species which occur in Britain each autumn are induced by some outside source of warmth. This work will be continued by reproducing warehouse conditions on a smaller scale at the laboratory. (*R. W. Howe*).

SURVEY OF CHEESE MITES

The survey of mite infestations of cheese has been continued from last year. The immediate aim of the survey was to determine the identity and relative importance of the mites attacking cheese in England, and the conditions under which infestation occurs, with reference to the types of cheese manufactured and imported, and to the methods of curing and storage. Visits were made to various representative centres of cheese production and storage.

It was found that the mould-ripened cheeses, particularly Stilton, were the most susceptible to infestation by mites, because of their mouldy condition and because they are ripened at high temperature and humidity, frequently over long periods. Storage hygiene is also important, particularly where there is no control of temperature. In home dairies and factories the principal focus of infection is the wooden shelving; unless this is cleaned often and thoroughly, mites are readily passed on to fresh batches of cheese placed upon it. Infestation picked up in this way seems to be maintained throughout subsequent storage. In a store holding cheese from different places, there are often differences in the species of mites on each batch, suggesting a number of different infestations picked up at an early stage rather than a common infestation from the store.

The species of mites found depends on the type of cheese and the physical conditions. Cheddar cured at atmospheric temperature supports *Tyrophagus* spp. and *Tyrolichus casei*, but in cool storage it is infested mainly by *Tyroglyphus farinae* and *Tyrophagus*, and by *Glycyphagus domesticus* and *G. destructor* chiefly when there is heavy mould growth. *Carpoglyphus lactis* was also found on Cheddar. On Stilton, cured at atmospheric temperatures, *T. farinae* is the main species, with *Tyrophagus* next in importance.

To provide information about the rate of damage by mites, an experiment has been set up at Reading University, in collaboration with the staff of the Department of Dairying. A series of cheeses, all infested with mites at the same time, is being kept for various periods and then reconditioned for use, by trimming. (*Miss P. L. Robertson*).

MITES OF THE GENUS *Tyrophagus*

A study has been commenced of the various forms of the genus *Tyrophagus* found on cheese and other substances. *Tyrophagus* has a world-wide distribution and occurs on a great variety of materials. It is common on cultivated mushrooms, on laboratory cultures of fungi and of insects, and on many stored foodstuffs such as cheese, ham, dried milk, chutneys, dried fruits, meals, grain, etc. It is recorded on the tissues of certain green plants.

Although a number of species and some varieties have been described, the status of many of these is doubtful. Experiments and observations are being undertaken to determine the range of variation of each type under the influence of varied food and other conditions, and the distinctness of the different types from each other, including their ability to interbreed. It is hoped that this work will provide interesting information on biological variation and also form the basis for a systematic revision of the genus. (*Miss P. L. Robertson*).

SURVIVAL AND INCREASE OF TYROGLYPHID MITES

A good deal of time has been spent on the examination and analysis of the great volume of accumulated data on the life history and physical ecology of the Flour Mite, *Tyroglyphus farinae*. Changes of junior staff have slowed down the progress of this work.

Shorter life history studies have been started on two other species of *Tyroglyphid* mites, *Tyrolichus casei* and *Tyrophagus castellanii*. As a first step, the relation between egg viability and relative humidity was studied at 15°C. A very small number of eggs of both species hatched at 60 per cent relative humidity—in contrast to the eggs of *Tyroglyphus farinae* which do not hatch at this humidity—but none hatched at 50 per cent relative humidity or below. At the above 70 per cent relative humidity a high proportion of all the eggs hatched.

As time permitted, these experiments were followed by others planned to provide data on the rates of development, adult life, egg production etc. of the two species. These experiments are still in progress, but some figures for *Tyrolichus casei* are now available and can be compared with those obtained earlier for *Tyroglyphus farinae*. The following figures are mean values. At 90 per cent relative humidity, 15°C., and with wheat germ as the food, the number of eggs per female for *Tyrolichus* was 294 against 460 for *Tyroglyphus*. *Tyrolichus* took 34·6 days to develop from egg to adult, whereas *Tyroglyphus* took only 20·2 days. The adult females lived for 71·4 days, compared with 42·4 days for *Tyroglyphus*. (*A. M. Cunnington, Miss S. R. Wiley, Miss R. Borrett, Miss M. C. Jackson, M. E. Solomon*).

HYPOPUS STAGE OF *Tyroglyphus farinae*

Like many other Tyroglyphids, the Flour Mite sometimes has interpolated in its developmental cycle a peculiar stage known as the hypopus, adapted for clinging to insects. Very little is known of the factors determining its appearance. No combination of constant temperature and humidity is alone sufficient to stimulate its production. Experiments are in progress to provide further information. Hypopi have sometimes been evoked when mites have been cultured on mouldy or decomposing cereal products, or on the rubbish from cultures of the moths *Ephestia* or *Hofmannophila*. (*M. E. Solomon, Miss R. Borrett*).

RESISTANCE OF *Tyroglyphus farinae* TO LOW HUMIDITY

Experiments to determine the degree of tolerance of the mite *Tyroglyphus farinae* to drying have been continued. Past work has shown that the eggs of this mite are more resistant to desiccation than the adult, although this resistance decreases with the age of the eggs. This result was confirmed in an experiment in which the relative resistances of all stages (except the hypopus) to drying at 50 per cent humidity at 20 °C. were measured. It was observed that the newly laid egg was the most resistant of all stages tested, and that the inert resting stages were more resistant than the active feeding ones. Larvae were extremely susceptible, some dying after only 7 hours and none surviving for more than 24.

In experiments at 15° and 20 °C., newly laid eggs were comparatively little affected by up to 2 days exposure to 50 per cent relative humidity, but after this period mortality increased sharply, particularly between the 2nd and 4th days, and rose to 96–98 per cent after 6–8 days. At 30 °C. 94 per cent of the eggs were killed after 1 day, 97 per cent after 2 days, and 100 per cent after 3 days exposure.

At 5° and 10 °C. no such simple correlation between mortality and time was found. A variable mortality, ranging from 32–72 per cent at both temperatures, occurred over periods up to 10 days, the maximum exposure period of the experiments. Within these limits mortality seemed to be independent of the period of exposure. Further experiments are now in progress. (*A. M. Cunnington, Miss M. C. Jackson*).

BIRDS' NESTS AS A SOURCE OF PESTS

The survey of the insects and mites occurring in birds' nests which was begun last year is now virtually complete. A preliminary account has already been published and a final paper is in preparation. Additional information on geographical distribution will be collected as opportunities arise to examine material from parts of the country which have not, so far, been visited. The chief results of this investigation may be summarized as follows:—

(1) The insect and mite fauna of a dry birds' nest corresponds almost species for species with that of a neglected food warehouse, except for those imported warehouse species which cannot overwinter in the open.

(2) The numbers of any species found normally far exceeds any previous records in the literature.

(3) The literature contains no estimate of the proportion of nests which normally contain a given pest. It was found that many of the more important species occurred in most nests. The table lists the most important species and gives for each the percentage of infested nests for five kinds of bird. In the case of the parasites *Metacoelus mansuetor* and *Apanteles carpatus* the number of infested nests is expressed as a percentage of the number containing the host moths.

(4) The frequent occurrence of the Australian Spider Beetle, *Ptinus tectus*, in nests suggests that these may have facilitated the spread of this recently introduced species across the country.

(5) Results of general entomological interest include the first records for Britain of the clothes moth, *Tinaea columbariella* and its Braconid parasite, *Apantales carpatus;* the discovery of two species of mite—

a *Glycyphagus* and a *Mealia*—apparently new to science; and a number of new records concerning parasites and predators of our common domestic pests. (*G. E. Woodroffe, B. J. Southgate*).

THE FREQUENCY OF OCCURRENCE OF SOME INSECT AND MITE PESTS IN THE NESTS OF VARIOUS BIRDS

	Percentage of nests infested				
	Sparrow	*Martin*	*Pigeon*	*Jackdaw*	*Swallow*
Hofmannophila pseudospretella	95	98	100	100	60
Endrosis lactella	68	67	51	72	0
Tinaea pellionella	22	10	40	81	22
Tinaea columbariella	86	80	68	38	63
Anthrenus verbasci	65	52	10	0	65
Attagenus pellio	45	50	50	81	50
Dermestes lardarius	2	2	28	0	0
Tenebrio molitor	50	4	65	12	15
Ptinus tectus	20	0	72	0	4
Ptinus fur	40	36	40	38	11
Ptinus sexpunctatus	11	21	0	0	0
Stegobium paniceum	2	0	60	0	0
Lepisma saccharina	10	0	32	38	0
Fannia canicularis	8	0	80	0	0
Metacoelus mansuetor *	42	65	36	40	0
Apanteles carpatus *	30	12	36	52	0
Scenopinus fenestralis	40	33	65	63	5
Lyctocoris campestris	40	31	67	50	5
Tyrophagus tenuiclavis	45	15	60	50	26
Tyroglyphus farinae	26	12	52	35	8
Glycyphagus domesticus	75	71	80	88	78
Mealia sp.	90	100	16	63	41
Cheyletus eruditus	75	92	82	44	14
Cheyletia flabellifera	25	0	0	25	0
Acaropsis docta	85	83	50	12	36
No. of Nests examined	80	56	29	16	30

* Percentage occurrence in nests containing host.

FIELD DISTRIBUTION AND HABITS OF THE THREE COMMON CARPET BEETLES

The three common carpet beetles—*Anthrenus verbasci*, *A. fuscus*, and *A. museorum*—are all found on flowers, especially Hogweed, *Heracleum spondylium*, in early summer. By collecting from these flowers it should be possible to compare the distribution of the three species over the country and also in different types of locality. Preliminary results indicate that some interesting differences occur. There are also differences in larval habitat in the field and these are no doubt associated with differences in behaviour. These field studies are an essential adjunct to the laboratory work on life history and behaviour in this group because of the importance of the outdoor phase of their life cycles. (*G. E. Woodroffe, B. J. Southgate*).

BEHAVIOUR OF THE CARPET BEETLE, *Anthrenus verbasci*

The reaction of the adult beetles to light has been observed to vary according to the source of the adults. All beetles collected from the inner sides of windows in March were found to walk in straight lines towards a source of light in a black box. Beetles collected from flowers in June behaved similarly, but about 10 per cent showed an indefinite reaction. Adults collected from cultures kept at 25 °C. walked in circles when subjected to unilateral illumination. Groups of adults from cultures at 20 °C. showed reactions varying with age. A series of factors possibly affecting the light reaction is being examined.

The reaction of larvae to light was always negative.

Adult beetles reacted clearly to humidity and preferred the lower relative humidity when given a choice between 30 and 50, 30 and 70, 30 and 90, 50 and 70, or 50 and 90 per cent.

Newly emerged larvae when given the same choices also preferred the lower relative humidities, whilst older larvae were indifferent.

In experiments with various odours the adults showed a distinct preference for low concentrations of the smell given off by the flowers of Hogweed. The preference was occasionally very pronounced but it often varied for unknown reasons. An attempt has been made to reproduce the odour chemically, but with little success. The reaction of adults to the smell given off by birds' nest material was also variable. The work is in progress. (*Mrs. G. M. Blake*).

LIFE HISTORY OF THE CARPET BEETLE, *Anthrenus verbasci*

Preliminary experiments on the duration of the various stages in the life-cycle of *Anthrenus verbasci* were started in September 1950. The approximate results are tabulated below:—

	Eggs, mean period	Larvae, mean period	Larvae, per cent mortality after 60 weeks	Pupae, mean period	Quiescent Adults, mean period
0 & 5 °C.	failed to hatch in 10 weeks				
10 °C.	failed to hatch in 10 weeks			77 days	35 days
15 °C.	35 days			35 days	15 days
20 °C.	23 days	35 weeks 1st 12 weeks of growth at 25 °C.	8	15 days	8 days
25 °C.	14 days	37 weeks	29	9 days	3 days
30 °C.	12 days	failed to pupate	83		
35 °C.		failed to pupate	100		
40 °C.			100 after 4 wks.		

Observations were made at 30, 70 and 90 per cent relative humidity at each of the temperatures studied. The results at 90 per cent relative humidity were discarded because mould attacked the food and altered the micro-habitat of the larvae. Otherwise, humidity differences had no significant effect. The complete life-cycle at 25°C. took just over nine months and it therefore seems unlikely that in the natural habitat there is more than one generation a year. Variable temperature work is being undertaken and the results of this may throw further light on the question. Its failure to complete the life cycle at 30°C. points to the temperate origin of this species. (*Mrs. G. M. Blake*).

MISCELLANEOUS INVESTIGATIONS

The life cycles of the Khapra Beetle, *Trogoderma granarium*, and the flour beetle, *Tribolium castaneum*, have been worked out at relative humidities of 10, 30, 70 and 90 per cent at temperatures 25, 30, 35, and 40°C. to check the conclusions drawn from experiences in Nigeria.

A preliminary comparison of the grain beetles *Oryzaephilus surinamensis* and *O. mercator* has been made at 70 per cent R. H. at 33, 25, and 20°C. on wheatfeed. *O. surinamensis* develops some ten to twenty per cent more quickly at all these conditions, but at 20°C. only a very small proportion of either species completed development.

At 33°C. *O. surinamensis* completes a developmental cycle in 3 weeks; at 25°C. in 5 weeks, and at 20°C. in 12 weeks; the corresponding figures for *O. mercator* are 3, 5, 6, and 15 weeks.

Specimens of the Canadian pest species *Ptinus villiger* were obtained from the Dominion Entomological Laboratory in Canada in the hope of investigating the biology of this species. Great difficulty has been experienced in obtaining eggs from this species and none of those obtained have been viable. Specimens in all stages of development have been subjected to low temperatures in an effort to simulate Canadian conditions, but this has not stimulated oviposition. (*R. W. Howe, H. D. Burges, Miss J. E. Currie, K. I. Street*).

GRAIN STORAGE AND MYCOLOGY

During the year under review certain aspects of the work of this Section have been suspended or slowed down, owing to the absence of some of the staff. Thus, Mr. Oxley was awarded a Nuffield Foundation Travelling Fellowship and visited Australia and New Zealand between October 1950 and August 1951 studying methods of storing and handling grain, and related research work.

Mrs. Hollier resigned her post as Mycologist in July 1951 and has not yet been replaced; Mr. Heslop was awarded a Treasury Bursary for full-time study at the University of London, and Mr. Disney has been away on military service throughout the year.

FIELD WORK ON GRAIN STORES

The study of supposedly "self-ventilating" concrete stave grain storage bins was completed. No effect of the self-ventilating feature on temperature or condition of the stored grain could be detected. (*J. P. Heslop*).

Thermocouples made at the laboratory, and installed temporarily in silos at Immingham, were used by the Infestation Control Division of the Ministry of Agriculture and Fisheries, to study temperature changes in stored grain. Con-

siderable experience in the construction of thermocouple ropes was gained in the course of this work. The results obtained are instructive and will enable a check to be made on theoretical forecasts of temperature changes. (*J. P. Heslop*).

RESPIRATION OF GRAIN IN RELATION TO MICRO-ORGANISMS

Respiration measurements, using a conductometric method of measuring carbon dioxide, mentioned in last year's Annual Report, have been made on wheat grain, with and without internal micro-organisms, maintained at different relative humidities and 25 °C. The results indicate that with normal grain, which has both external and internal micro-organisms, there is a sharp increase in the rate of respiration as the moisture content of the grain rises above 16 per cent. This rise is accompanied by the development of visible external mould, especially at moisture contents of 18 per cent and above.

Wheat free from internal fungus, produced by enclosing the developing ears in desiccator flasks, as described in the Annual Report for 1948, has a respiration rate at low moisture contents (below 16 per cent) very similar to that for normal grain, but at higher moisture contents the rate also increases rapidly and to almost the same extent as that of normal grain; at moisture contents of 18 per cent and over it is again associated with visible external mould growth.

On the other hand, grain which had been sprayed during development with 8-hydroxy quinoline sulphate, and thereby rendered free from both external and internal micro-organisms, has a much smaller increase in respiration at moisture contents above 16 per cent, and at 18 per cent moisture it shows no sign of external mouldiness. For example, in one series of experiments such wheat was found to have, at 17·5 per cent moisture content, a respiration rate of 2·5 mg. CO_2/100g. wheat/24 hr., compared with 25 mg. for normal grain and 26 mg. for the grains allowed to develop in desiccator flasks. It is presumed that the failure of external moulds to develop is due to the presence of a residue of 8-hydroxy quinoline sulphate on the surface of the grains.

It therefore appears that the subepidermal mycelium had no effect on the respiration of damp grain, and that the increase in CO_2 production at moisture contents above 16 per cent was due to the development of external moulds. At moisture contents below 15 per cent there are apparently no significant differences in the amount of respiration in normal and fungus-free wheat. Confirmatory experiments are in progress. (*Miss M. B. Hyde*).

EFFECT OF STORAGE HUMIDITY ON THE SUBEPIDERMAL FUNGI OF WHEAT GRAINS

It has been suggested by some workers that the sub-epidermal fungi of wheat grains are probably dead and therefore incapable of respiration or further development. In order to check this statement small quantities of wheat have been stored during the past two years at various relative humidities and at 25 °C. for periods up to 27 weeks, and the amount of subepidermal mycelium has been determined at intervals.

The results show that low humidities (55 per cent or less) have little appreciable effect on the amount of internal mycelium, nor is there any noticeable development of external mould under these conditions. At higher humidities, however, particularly above 85 per cent, there is considerable development of mould on the outside of the grains, this being preceded by a musty odour, after about 12–14 weeks storage. At this humidity, and also at 70 per cent R. H.,

there is a progressive increase in the amount of subepidermal mycelium, which reaches a maximum after about 8–12 weeks, according to the type of wheat. It is thus clear that the subepidermal fungi are alive. At 85 per cent R.H., and sometimes at 70 per cent this is followed by a fall in amount of internal mycelium, contemporaneous with the development of external mould. This reduction in internal fungus may possibly be due to some antibiotic effect of the external mould fungi, resulting in resorption of some internal hyphae. In most samples, further storage beyond 18–20 weeks results in a second increase in the amount of internal mycelium, thought to be due to the penetration and spread of the external moulds beneath the epidermis.

At the termination of the longest period in this experiment (27 weeks) the grains were examined for the presence of micro-organisms. The fungi normally associated with grain were found at the lower humidities only. At 85 per cent only 2 genera *Penicillium* and *Aspergillus*, were present, and were obtained from all grains, with and without surface sterilization. There was complete suppression of germination in the grains at this humidity and exposure period. (*Miss M. B. Hyde and D. Budd*).

EFFECT OF FUMIGATION ON GRAIN MICRO-ORGANISMS

The respiration experiments had indicated that external organisms appear to be responsible for the increased respiration of damp grain, and it was thought that if the mould flora could be killed or restricted in development there might be less danger of heating on subsequent storage. Some preliminary experiments have, therefore, been carried out to determine the effect of some insecticidal fumigants on the external and internal fungi normally associated with wheat grain.

In small scale tests both ethylene dichloride and carbon tetrachloride were found to be non-toxic to the fungi even in high concentrations (300–400 milligrams per litre) over 168-hour periods. They also had no harmful effect on the viability of the wheat

In larger scale experiments, methyl bromide was found to be toxic to the moulds, but also to inhibit the germination of the grain, at a concentration of 37·5 mg./l. for 24 hours; living fungi and viable wheat were still present after exposure to a concentration of 10·5 mg./l. for 46 hours. Thus with exposures sufficient to kill the fungi, and far in excess of those used against insects, the germination of the grain was affected.

Tests with ethylene oxide have so far been inconclusive, but the results agree with those for methyl bromide in that at high concentrations and long exposures the viability of the grain is affected.

It is intended to extend these preliminary experiments, using other substances and exposures. (*G. Ayerst, S. G. B. Heuser*).

"BLACK POINT" IN STORED WHEAT

In the course of a world survey carried out to determine the distribution of the subepidermal fungal mycelium in wheat (see Annual Report for 1949) it was noticed that samples from a number of countries contained grains with a brown discolouration of the epidermis in the region of the embryo. Such a discolouration is known in commerce as "black point" or "kernel smudge", and although generally regarded as a disease of quality, is known to be caused by micro-organisms. It was thought that these micro-organisms, if still alive, might be

a cause of deterioration of grain in storage. Examination of the survey sample showed the disease to be almost universal in distribution, some 64 of the 53 samples received having more than 4 per cent of the grains infected, a proportio which could be readily detected by rapid examination. In 15 samples, 15–2 per cent of the grains had "black point" symptoms, and in one sample abou 75 per cent of the grains were affected.

"Black pointed" grains have occurred occasionally during the past fou years in wheat grown at the Pest Infestation Laboratory, and affected grains fron the 1949 and 1950 crops have been investigated. In general the only fung isolated from surface-sterilized and unsterilized grains were the species o *Alternaria*, *Cladosporium*, *Pullularia*, *Penicillium*, etc. previously shown to b present as subepidermal mycelium, or as surface contaminants, in norma healthy grain, but in a few instances isolations taken only from the discolourec portion of the epidermis yielded *Helminthosporium* sp. and bacteria, which have been stated by other workers to be two of the causes of "black point"

Attempts to induce "black point" by inoculating developing ears with these organisms are proceeding. (*Miss M. B. Hyde*, *D. Budd*).

MYCOLOGICAL FOOD STORAGE PROBLEMS

An interesting mycological problem which has been investigated during the year has been the possible cause of a white deposit which had developed on a consignment of Brazil nuts during shipment. It was at first thought that common mould fungi, particularly species of *Aspergillus*, were largely responsible, but these organisms were later also obtained from normal nuts. Further culturing produced a number of species of Actinomycetes, and it is now thought that these may be the cause of the deposit, which appears to consist of a fine fungal mycelium. Attempts to cause the deposit to develop on normal nuts by inoculating them with the Actinomycetes and exposing to conditions of high temperature and humidity, such as might have prevailed during shipment, have so far been unsuccessful. (*G. Ayerst*, *Miss M. B. Hyde*).

INSECTICIDES

The work of the Insecticide section has been affected by considerable changes of staff during 1951, the greatest effect being on the work on insecticides for use against warehouse insects.

STATISTICAL ASPECTS OF INSECTICIDAL ACTION

The quantal response to a mixture of insecticides having similar mechanisms of physiological action has been investigated in collaboration with Mr. R. L. Plackett. The relation between the response to a mixture and the responses to the components applied alone can be more general than was thought by previous investigators. A preliminary publication has been prepared. (*P. S. Hewlett*).

ACTIVATORS IN HEAVY-OIL SPRAYS

Flour Beetles, *Tribolium castaneum*, have been treated at a fixed level of deposit by a direct spray technique with pyrethrins and piperonyl butoxide in Shell oil P31. A mathematical expression was found which would relate probit mortality to the concentrations of pyrethrins and piperonyl butoxide over wide ranges of concentrations.

On the bases of this work, an experimental design was chosen to allow quantitative comparison of the intensities with which different activators activate a given insecticide, or with which different insecticides are activated by a given activator. Pyrethrins, allethrin, and BHC, in combination with two commercially prepared activators A and B, were used in a series of comparisons. It was found, for example, that A activated pyrethrins about 6 times as intensely as did B, but activated allethrin only about 1·8 times as intensely as did B: pyrethrins and allethrin were activated about equally by B.

A less detailed series of similar tests showed that both pyrethrins and BHC were activated by four compounds having the methylenedioxyphenyl radical in common. (*P. S. Hewlett, Miss B. Clayton*).

IMPREGNATION OF SACKING

The protection against infestation afforded by jute sacking impregnated with pyrethrins or piperonyl butoxide or a mixture of the two has been investigated in laboratory tests. The fabric was impregnated at the required levels and made up into suitable small sacks by the British Jute Trades Research Association, who are collaborating in the investigation. Hessian and twill sacklets filled with a mixture of wheat and wholemeal flour were exposed at 25°C. to infestation by the Granary Weevil, *Calandra granaria*, and the Flour Beetle, *Tribolium castaneum*. In one experiment the beetles were allowed a choice between treated and untreated sacklets, and in another they were allowed no choice. Similar conclusions were drawn from the two experiments.

All the pyrethrin and pyrethrin+piperonyl butoxide treatments greatly reduced the likelihood of infestation. Piperonyl butoxide, though by itself ineffective, increased the effectiveness of the pyrethrins. Sacking of both types impregnated with approximately 0·1 per cent by weight of pyrethrins or 0·05 per cent pyrethrins + 0·5 per cent piperonyl butoxide gave virtually complete protection against both species of insect. As illustration of the decisive results obtained, whereas a population of the order of 1000 insects could result from penetration into and breeding within an untreated sacklet, no living insects would be found inside a suitably treated sacklet, similarly exposed to infestation.

The tests were performed with freshly treated sacking: the durability of the impregnation treatments, and other points of practical importance, now need to be investigated. (*Miss B. Edwardes Evans, P. S. Hewlett, E. A. Parkin*).

PYRETHRUM POWDER FOR THE CONTROL OF THE CACAO MOTH ON GRAIN

In the report for 1950, a brief description was given of an experiment in which 500 tons of grain stored in bulk was dusted on the surface of the pile with pyrethrum powder to see if this treatment would give protection against infestation by the Cacao Moth, *Ephestia elutella*. The results were somewhat inconclusive and it was hoped that an opportunity would occur to repeat the experiment in 1951. Although preparations were made to carry out the trial it proved impossible, at the last minute, to arrange the reservation of a bulk of suitable grain for the necessary period of observation. (*E. A. Parkin, Miss W. M. Eustace*).

INSECTICIDAL SMOKE TREATMENT OF A FARM GRANARY

The experimental treatment of a farm granary in 1950 provided some interesting information on the effect of the insecticidal residues from smokes upon the population of insects hidden deeply in cracks and crevices and thus not

removed during the preliminary cleaning processes. A similar treatment was undertaken in a different granary in 1951, but with the smokes used in the reverse order, i.e. D.D.T. followed six days later by BHC. Moreover the building was much less suited to treatment than that dealt with in 1950, as it had double walls of overlapping wooden boards; in the cavity between was a considerable amount of grain heavily infested by mice and insects. The principal insects present were the Saw-toothed Grain Beetle, *Oryzaephilus surinamensis*, the Cellar Beetle, *Cryptophagus cellaris*, the Granary Weevil, *Calandra granaria*, and the Flat Grain Beetle, *Laemophloeus ferrugineus*. The size of the population was eventually estimated from periodic counts made on twelve sample areas, each one foot square, on the floor.

At the completion of cleaning the granary, relatively few insects had emerged from cracks and crevices into the counting areas, but when the granary was opened 17 hours after starting the D.D.T.-smoke generators, hundreds of insects were lying dead or affected in each area. As observations continued at intervals and a gamma-BHC-smoke treatment was applied followed finally by another D.D.T.-smoke treatment, the numbers of insects killed rose steadily until it was estimated that about 350,000 had been accounted for. By the time observations were stopped it seemed that few insects remained alive out of the enormous original population.

These results confirmed those obtained in the previous experiment that useful observations of the effect of the insecticidal treatment could be made by a simple sample-counting technique; that insecticidal smokes have poor penetrating powers into cracks and crevices in which may be sheltering large insect populations; but that, provided intensive cleaning has preceded the treatment, the insects are trapped by the residual insecticidal film on the floor during the following several weeks with a consequent enormous reduction in the surviving population. (*E. A. Parkin*, *Miss W. M. Eustace*).

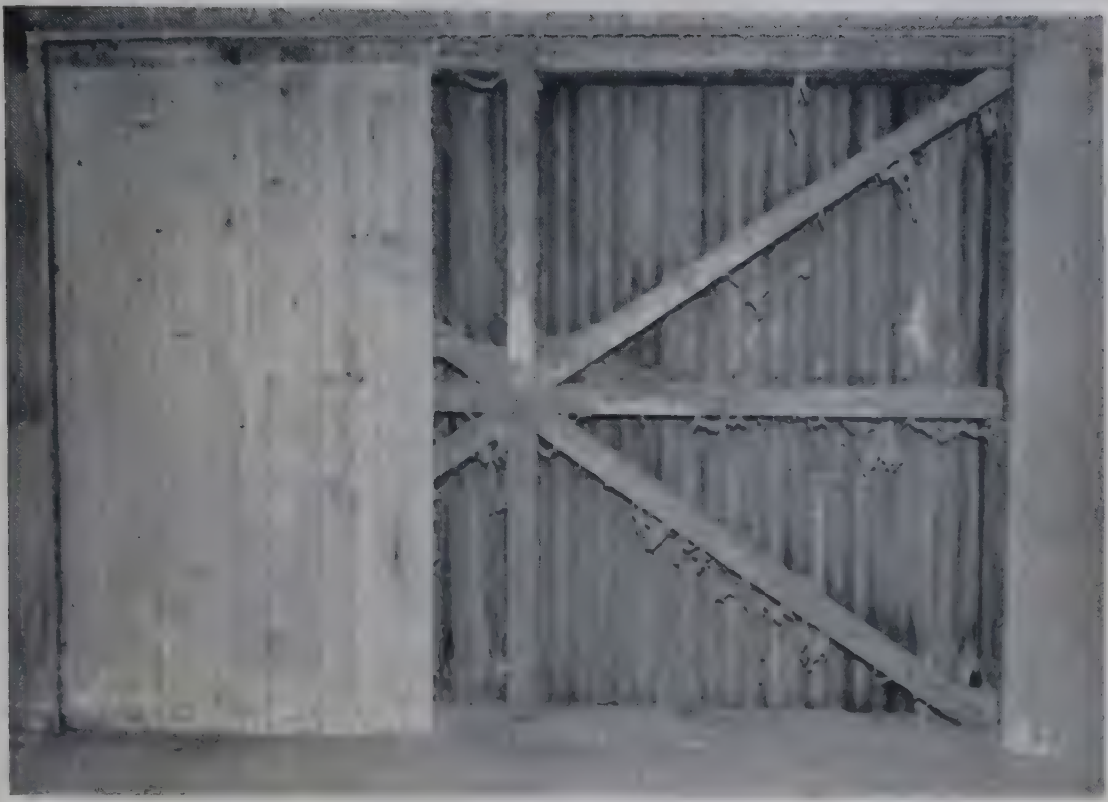
ACARICIDAL PROPERTIES OF INSECTICIDES

The preliminary investigation mentioned in the last Annual Report was continued intermittently until brought to an end by staff changes. Tests of gamma-BHC, Lethane 384, and piperonyl butoxide in solution in odourless kerosene showed that they were as toxic to the Flour Mite, *Tyroglyphus farinae*, as when tested previously in Shell oil P31. This held good irrespective of the sample of odourless kerosene used as solvent but, with less strongly acaricidal substances, some differences were found in effectiveness according to the sample of kerosene used. It is hoped to find an opportunity to take this work up again soon.

A simple laboratory test of 2 per cent of piperonyl butoxide in kaolin indicated that this dust had good acaricidal properties. (*E. A. Parkin*. *Miss B. Edwardes-Evans*).

MICRO-DROP APPLICATOR

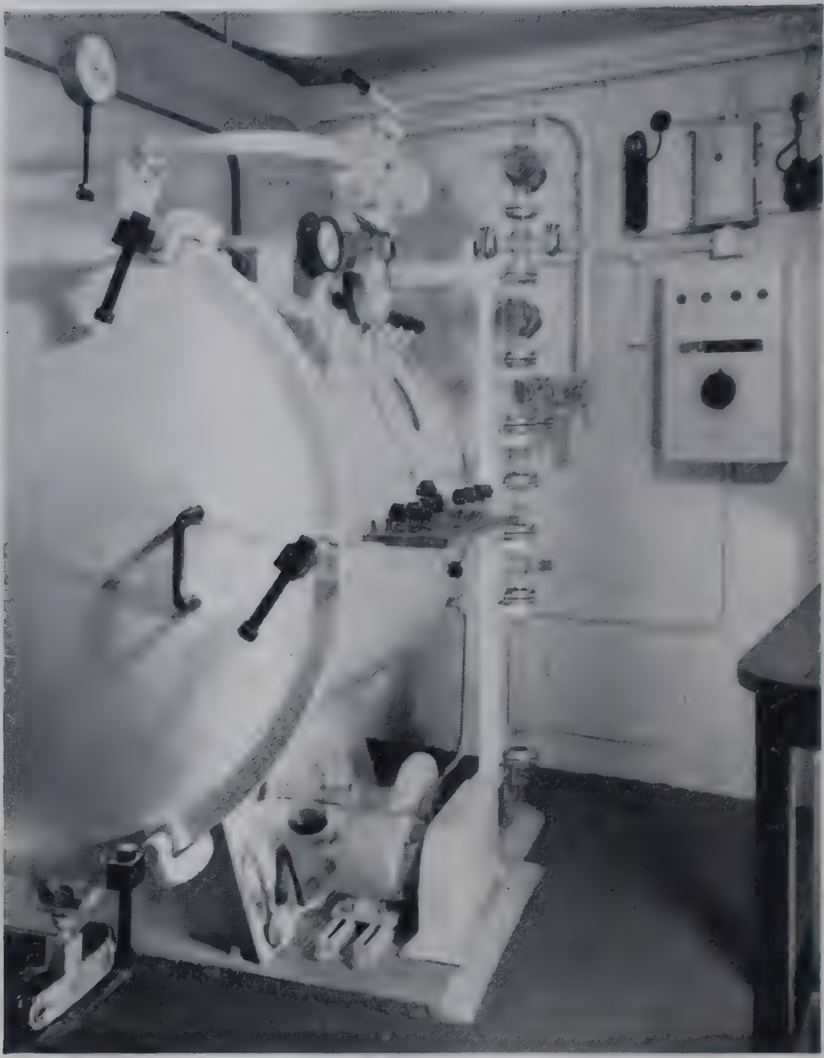
Owing to pressure of other work the micro-drop applictor has not been used on a large scale. However, a simple immersion method has been devised for measuring the volumes of single drops of dyed P31 delivered. The variation in the size of individual drops was found to depend upon the mean drop size. Thus the standard deviation of individual drop volume was about 10 per cent at a mean volume of 0·02 cu.mm., falling to about 5 per cent at 0·10 cu.mm., falling



(A) *Infested material found in a wall cavity after removal of boards*

(B) *Experimental treatment of railway sidings infested by migrating blowfly larvae*

PLATE I



(A) *Fumigation chamber in air-conditioned room*

(B) *Interior of chamber showing light alloy channels to take insect cages*

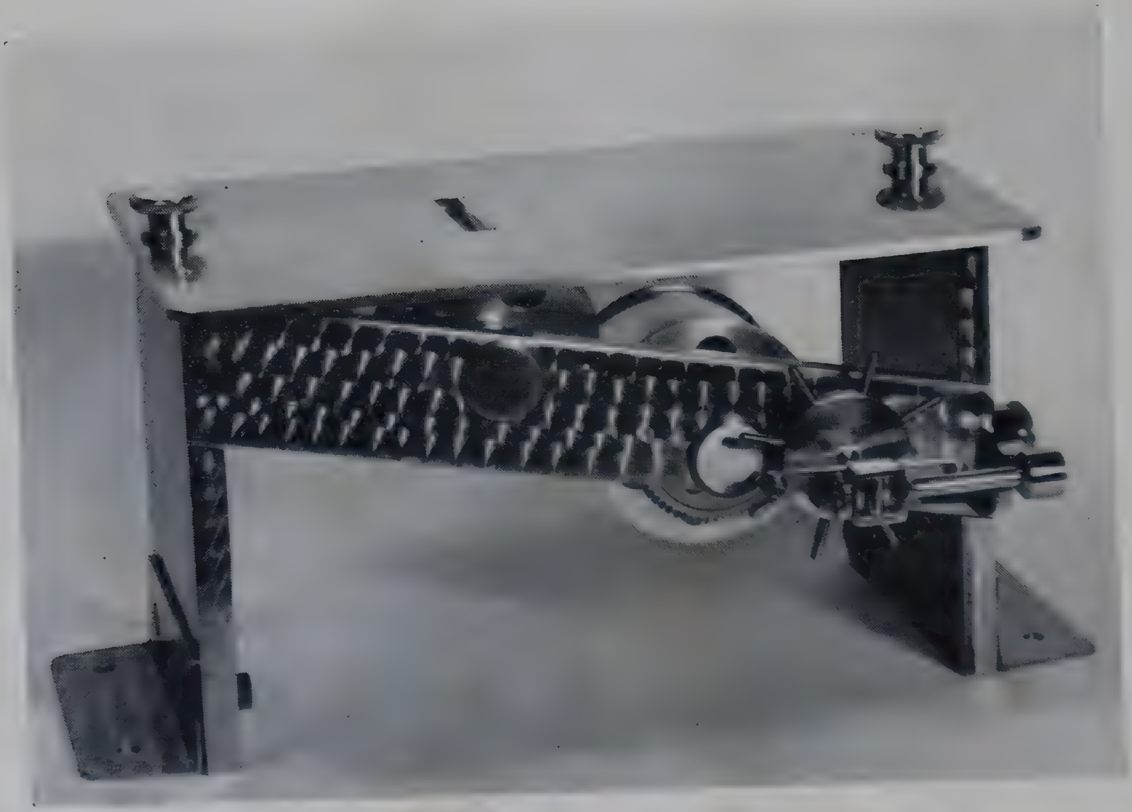
PLATE II

(A) *Preparation of samples of insects for test*

(B) *Introduction of insect cages to fumigation chamber*

PLATE III

(A) *Warburg manometers used for the study of cellular metabolism*



(B) *Automatic scanning device for radio-chromatograms*

PLATE IV

further to about 2·5 per cent at 0·30 cu.mm. Another method, developed by other workers, was compared: this depended on measuring the diameter of oil lenses, derived by firing the drops on to glass surfaces coated with dimethyl-dichlorosilane. The derived standard deviations for apparent drop volume were much higher, indicating considerable errors in the lens method.

In the calibrations just described the applicator was fitted with a hypodermic needle, attached to the syringe barrel, passing through an air jet. This arrangement was very liable to go out of proper adjustment when the solution was changed. The difficulty has been overcome by making a part incorporating the needle and jet into one assembly. The directional accuracy of fire has been maintained; individual drops do not deviate by more than about one degree of arc from the mean path.

Homogeneous concentration-mortality data for pyrethrins, D.D.T., and BHC, have been obtained when *T. castaneum* beetles were each treated dorsally, between pro- and mesothorax, with 0·05 cu. mm. of solution. (*P. S. Hewlett*).

MOTHPROOFING TESTS

The Larval Test Sub-committee of the Moth and Dermestid Beetle Proofing Committee, on both of which the Laboratory is represented, drafted at the beginning of the year a tentative specification of procedure for the determination of mothproofing efficiency of treatments incorporated in smooth woollen cloths. The specification described a standard technique of test and has an appendix setting out the method for rearing and handling the test insect, the Common Clothes Moth, *Tineola bisselliella*. The Laboratory has collaborated with the other members of the Sub-committee in carrying out a large-scale experiment according to the specification to get more data on which to base decisions on (*a*) the minimum mean weight loss which must be sustained by the untreated patterns of standard cloth if the caterpillars are to be judged sufficiently voracious for the test to be valid and (*b*) the maximum weight loss which can be tolerated from a pattern which is judged to be proofed. Some preliminary work has been done to determine the weight loss tolerance for a blanket material with a raised surface.

The main Committee was asked by the International Wool Trades Organization to send a delegate to a conference in Paris in April to discuss the possibility of agreeing upon an internationally acceptable procedure for determining the resistance of treated wool materials to attack by Clothes Moths and Carpet Beetles: Dr. E. A. Parkin attended as one of the two observers accompanying the British delegate. At this conference the differences between the British and Swiss specifications were considered and, to settle some major points at issue, tests involving seven laboratories in three countries were planned. These tests have now been carried out with the Common Clothes Moth, *Tineola bisselliella*, and the Furniture Carpet Beetle, *Anthrenus vorax* as test insects; the results of the tests are now being collated centrally for discussion.

For these tests considerable numbers of larvae of *A. vorax* have been reared under standardized conditions, starting with a Dutch strain from the Vezel-instituut, Delft. It is hoped soon to have an opportunity to compare this strain with the strain which has been cultured for some years in the insectaries at the Pest Infestation Laboratory. These insects grow well at 28 °C. and 70 per cent R. H. on a medium of wool yarn supplemented by a mixture of 10 parts yeast and 1 part cholesterol.

Several ancillary experiments have been made with *T. bisselliella* to obtai more information upon certain aspects of the testing procedure for assessin mothproofing. The effect of treating a central area of each sample for test wit a bait spot of yeast extract, and not yeast suspension as was used previousl was to bring about a sharper distinction between proofed and borderlin treatments without significantly altering the borderline concentration of moth proofing agent. The yeast extract gave better results than the suspension.

In testing the effect of different numbers of larvae per sample of untreate cloth, overcrowding, with consequent disturbance during feeding, did not appea serious at any population level tested although the amount of cloth eaten per lar vae decreased slightly as the number of larvae per sample increased. The 10–2 larvae now being used in mothproofing tests are therefore a reasonable numbe for the size of sample.

The rate of growth of larvae has been determined at closely controlle temperatures by rearing them in jars completely immersed in water-baths an fitted to allow ventilation by the slow passage of a current of air of controlle temperature and relative humidity. Four jars were used at each of the fou experimental temperatures 20, 21, 24, and 25 °C., one jar being removed fo examination at each of the four selected ages of the larvae viz. 25, 30, 35, an 40 days. From each jar, when it was removed for examination one hundre larvae were assembled at random and weighed. The data obtained are show graphically in Fig. 1, the two pairs of curves clearly demonstrating the importanc of keeping breeding temperatures well within the range of $\pm 0{\cdot}5$ °C. if larvae ar to be reared in a standard manner so as to have them of a given weight at a give age. It may be noted that the change of slope at the upper end of the 25 °C curve is probably due to incipient pupation.

When batches of larvae of different ages were exposed for 14 days at 25 °C on untreated cloth, the maximum loss in weight from the fabric occurred wit larvae slightly smaller than those selected for use in the standard test, but th latter are as small as can conveniently be handled. When larvae of the sam age were sorted into three groups on the basis of their size, the largest larva did the most damage to untreated cloth. (*E. A. Parkin, Mrs. P. J. Maycock Miss D. G. Blackman*).

CONTROL OF CLOTHES MOTHS

Some tests have been done to asses the value of mixtures of insecticides a dusts against larvae of *Tineola bisselliella*. The dusts contained combination of 1 per cent and 5 per cent DDT with 0·02 per cent, 0·1 per cent and 0·5 pe cent pyrethrins; also 1 per cent and 5 per cent DDT with 0·5 per cent and per cent gamma-BHC. The rate of knock-down with DDT and pyrethru mixtures corresponded roughly with that expected from the pyrethrum con tent alone, whereas the rate of kill corresponded to that expected from the DD alone and was slower than that for pyrethrum alone. In most instances th rate of kill decreased as the concentration of pyrethrins with a particular level o DDT increased, indicating some degree of antagonism between the two insecti cides under these experimental conditions. With the mixtures of DDT an gamma-BHC the rate of knock-down tended to be like that of the BHC alon whereas the rates of kill corresponded roughly to those of the DDT alone, bu were only a little slower than those obtained with BHC.

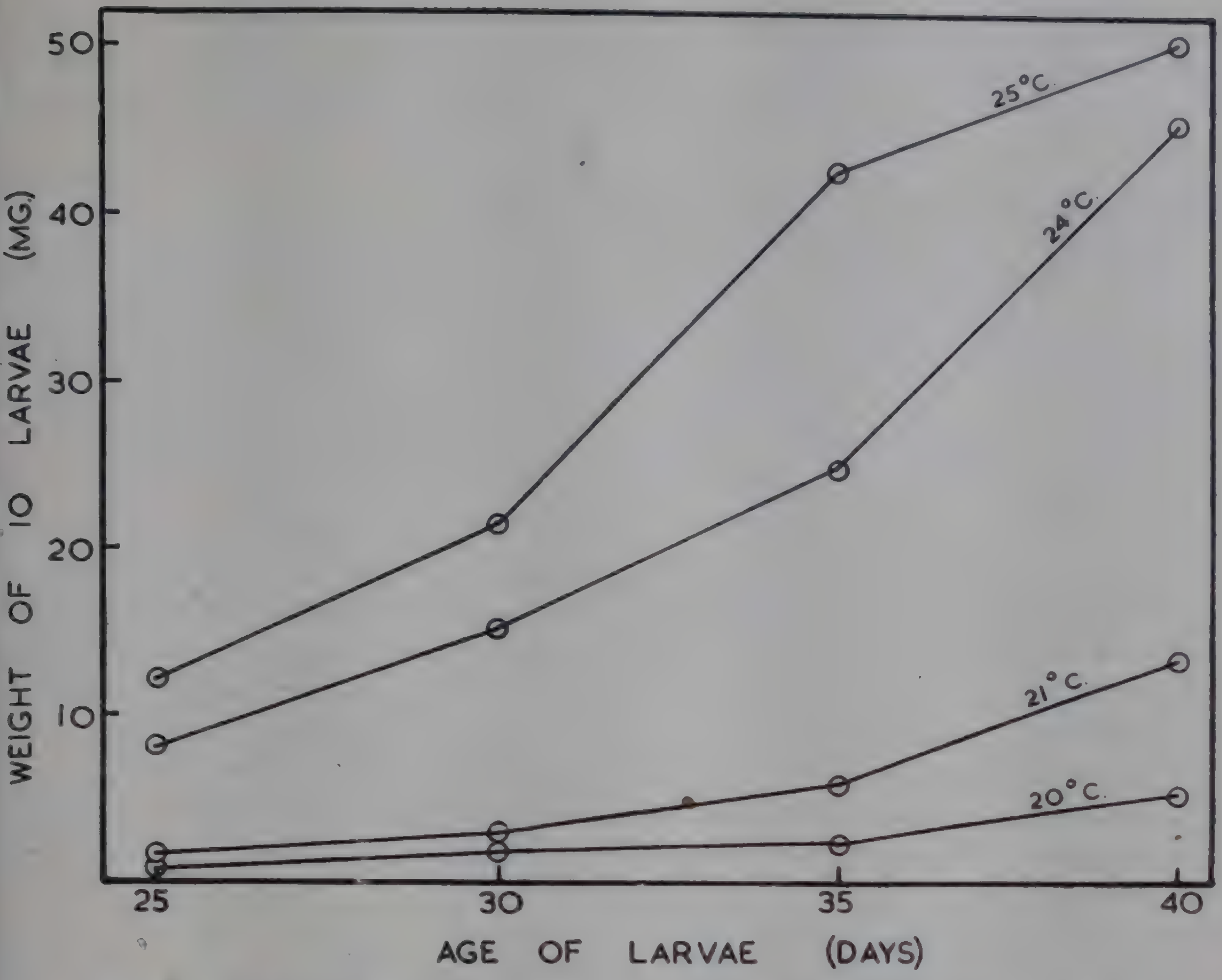


FIG. 1.—*Relation between age and weight of larvae of* Tineola *at different temperatures*

To determine the value of various ways of wrapping cloth to protect it against Clothes Moth attack, pieces of flannel were wrapped in brown kraft wrapping paper secured in various ways and were exposed to attack by free-flying moths. Three types of package were prepared; the first had flannel folded in one layer of paper left unsealed; the second had flannel wrapped in one layer of paper which was then sealed with cellulose tape; and the third had flannel wrapped in two layers of paper with each layer sealed separately. One set of these packages was placed with unwrapped cloth in a single glass jar so that moths had a choice of egg-laying sites and there was a possibility of larvae migrating from heavily infested unwrapped cloth into wrapped packages; a second set was placed singly in separate jars. It was found in both tests that double wrapping and sealing gave complete protection, whereas single wrapping and sealing would probably give adequate protection in practice (five moths of the first generation were found in this package when all were stored together and two when they were stored separately). Wrapping without sealing gave inadequate protection.

A further test was performed using flannel wrapped in one layer of paper with the edges folded together and tied with string. Four of these packages were prepared as follows: one had 10 per cent DDT dust sprinkled over the flannel; a second had flakes of naphthalene folded in the flannel; a third crystals of paradichlorbenzene; the fourth was untreated. The packages were placed separately in jars. It was found that the untreated package became heavily infested while the other three appear on preliminary inspection to be completely protected.

Some work has been started to determine the resistance to *Tineola bisselliell* to insecticidal sprays but the investigation has not yet proceeded far enoug for any results to be reported. (*Mrs. P. J. Maycock*, *Miss D. G. Blackman*)

CONTROL OF BLOWFLIES IN SLAUGHTERHOUSES

Two papers have been published giving accounts of the progress of this work

The full-scale experiment, begun in 1948, at a large slaughterhouse showed by the end of 1950, that improved hygiene prevented breeding of blowflies o the premises and that chemical control prevented the immigrating adults fron building up to a major infestation. In 1951, the plan of the experiment wa changed so as to separate the effects of improved hygiene and chemical contro and it has now been shown that chemical control measures will be necessar so long as blowflies breed in large numbers beyond the slaughterhouse premises Control measures have been applied experimentally at a small provincia slaughterhouse where conditions were very different from those at the larger more highly organised premises. The resulting data have not yet been fully analysed but it is clear that a considerable reduction of the blowfly populatio was achieved.

With the co-operation of the Royal Sanitary Institute, the help of mea inspectors representing 14 local governments in 12 counties was obtained t collect eggs of blowflies from carcasses in slaughterhouses. This investigatio was designed to determine the severity of the "blown" carcass problem, th species of fly causing damage, the most attractive types of meat, etc. Dat obtained from this survey have not yet been fully analysed but have confirmed th impression that Bluebottles (*Calliphora* spp.), although normally representin only about 5 per cent of the population, are responsible for more than 90 pe cent of the blowfly damage to carcasses.

Laboratory studies on the migration of larvae have been continued using clockwork apparatus to trap migrating larvae at hourly intervals. The pea period of migration occurred on the sixth night after oviposition, betwee 10 p.m. and 2 a.m. for *Lucilia sericata* and between 10 p.m. and midnight fo *Calliphora erythrocephala*. (*A. A. Green*, *A. M. Simmonds*).

CONTROL OF BLOWFLIES IN REFUSE

In both the 1949 and 1950 Reports it was pointed out that many of the adu flies infesting slaughterhouses originated from other breeding grounds and it obvious that the satisfactory control of such flies can take place only at sourc where measures can be taken to prevent breeding. One such source of maj infestation was a large refuse collecting and sorting depot in London. With th co-operation of the Railway Executive and the local Borough Council it ha been possible during the past summer to carry out extensive trials using vario formulations of BHC and DDT for the control of migrating larvae and emergi adults. (Plate I(B)) As a result, it is anticipated that recommendations can made for economical measures to reduce such an infestation to 1 per cent or le of its original level. (*A. A. Green*, *Miss M. J. Kane*).

OVERWINTERING OF HOUSEFLIES AND BLOWFLIES

Houseflies (*Musca domestica*) and Blowflies (*Lucilia sericata*, *Phorm terrae-novae*, *Calliphora erythrocephala* and *C. vomitoria*) were kept in an u heated, fly-proof, wooden building during the winter of 1950–51 but none su

ived the cold weather or laid eggs. It seems unlikely therefore that the first eneration each year, of these species, results from adults which have over-vintered in unheated sheds or barns.

In collaboration with a large multiple store, seven of their premises were earched for flies during January and February, 1951. Seven houseflies only vere found, all in one store and all males; they proved capable of fertilizing aboratory-reared females. No evidence was obtained that flies re-infest tores by overwintering as adults on the premises.

Dung and laboratory-prepared fly food infested with housefly larvae were left outdoors at the Laboratory during the winter. Most larvae were drowned uring the very wet winter and no adults emerged in the spring. (*A. A. Green, 1. M. Simmonds, Miss M. J. Kane*).

'LY BREEDING IN WOOL WASTE

An enquiry was received asking whether the large dumps of wool waste from ome textile factories could become breeding grounds for houseflies. Laboratory experiments showed that, when the waste was wet and decomposing, flies would oviposit on this material and that some larvae could develop and emerge as adults. Although larval development is slow and the resultant adults stunted, he possibility cannot be ignored of infestation by flies of dumps of this rotting naterial. (*A. A. Green, Miss M. J. Kane*).

ABORATORY TESTS OF FLY LARVICIDES

Using a 1:70 dilution of a proprietary 20 per cent BHC emulsion for larval control, it has been shown that *Lucilia* are more susceptible than *Calliphora* and hat at least 85 per cent of larvae in treated soil are killed. To achieve this level of larval mortality the soil was wetted to a depth of 2 in. which, in practice, would involve high and expensive dosage rates.

Tests with dieldrin indicate that emergence of adult flies of *Musca domestica*, *Calliphora erythrocephala*, and *Lucilia sericata* can be completely prevented by mixing in 4–5 parts insecticide per million of larval food. Effective control can probably be achieved at lower dosages for the few adults which emerged soon died. (*A. A. Green, Miss M. J. Kane*).

LABORATORY TESTS OF FLY SPRAYS

Tests of space sprays containing sesame oil have been carried out on behalf of the War Office. With a view to providing alternative formulations, several other activators for pyrethrum have been tested in fly sprays and a recommendation made concerning one of them. (*E. A. Parkin, A. A. Green Miss M. J. Kane*).

TESTS OF PYRETHRUM STANDARDS AGAINST HOUSEFLIES

Tests were continued on solutions containing 0·1 per cent pyrethrins which were prepared as possible standards for use in biological assays in this country. In tests against houseflies there was no evidence of any loss of toxicity during 12 months storage at 20°C.

The Laboratory has played an active part in meetings of interested workers called to discuss the pros and cons of these alternative pyrethrum standards. In view of information that workers in the U.S.A. were also actively engaged in considering ways in which the existing standard could be improved, the possi-

bility of co-operative action between this country and the U.S.A. is being e amined to erect a pyrethrum standard solution for biological assay which wou be internationally acceptable. (*E. A. Parkin*, *A. A. Green*, *Miss M. J. Kane*).

CONTROL OF HOUSEHOLD INSECTS

Pressure of work on the field trials of control of blowflies has necessitated reduction in the time spent on *ad hoc* methods of control.

Successful control of the Common Black Ant, *Lasius niger*, has been achiev with poison bait in a factory canteen and in a dwelling house. Information the American literature indicated that chlordane was especially useful for co trolling ants so a small supply was obtained and tried. Excellent results we given against *L. niger* by protective bands of 2 per cent chlordane in kerose painted round floor margins and skirting boards in a school and in two dwelli houses. Infestations of a large hospital and of a biscuit factory by Pharaoh Ant, *Monomorium pharaonis*, were inspected and advice given upon the app cattion of an experimental sample of 2 per cent chlordane. A report has not y been obtained from the hospital, but the factory has stated that no ant infestati has been seen during the twelve months following the treatment.

Further observations have confirmed that the treatment with pyrethrum a DDT dusts in 1950 of cockroaches in a dwelling house gave complete control the fairly localized infestation. Treatment of an infestation by the Germ Cockroach, *Blatella germanica*, in a canteen by means of DDT smoke gave least 99 per cent control, as indicated by the few insects seen after a seco treatment.

Advice has been given by correspondence to Government Departmen Local Government, industry, and private individuals, on control of an booklice, carpet beetles, clothes moths, cockroaches, earwigs, flies of vario sorts, silverfish, and wasps. (*E. A. Parkin*, *A. A. Green*, *Miss M. J. Kane*).

TESTS OF NEW SYNTHETIC MATERIALS AS INSECTICIDES

The only work done under this heading during the past year has been occ sional tests of substances as received from Dr. S. H. Harper of King's Colleg London, and prepared in his investigations into the synthesis of the pyrethrin (*E. A. Parkin*, *A. A. Green*, *Miss M. J. Kane*).

VARIATION IN INSECT RESISTANCE

Work has continued steadily on the measurement of the resistance of t special stock of the Flour Beetle, *Tribolium confusum*, to methyl formate. The and subsidiary tests have involved about fifty fumigations and 60,000 beetle

A constant aim of this work has been to improve the homogeneity of t results from the standard tests and during the year various fumigations we carried out to investigate possible sources of error and reduce variability. small transportable dust extraction apparatus was brought into use to enable culturing to be done without removing the insects from the breeding room whi is maintained at 25 °C. and 70 per cent R. H. In the course of testing the effe of this change, it became clear that the resistance of the stock had decreas significantly and that low values of the LD50, which previously occurred rarel were now occurring regularly. Whilst causes for this drop in resistance we being sought, the resistance which had remained low from February to Apr gradually increased during May and by June had regained its former lev

No definite explanation can yet be offered for the return of the "normal" resistance of the stock, but it is suspected that the explanation lies in the possibility of a slight fall in the temperature of the breeding room which was not detected for some time. This point is now being watched more carefully, but in the meantime has imposed a delay in obtaining results.

As a subsidiary investigation, a start has just been made on an attempt to produce a resistant stock of the beetles by exposure to sublethal dosages of the fumigant. Quick progress cannot be expected in view of the relatively slow rate of breeding of the insects. (*J. A. Hope, K. G. Gostick*).

FUMIGANTS

The main emphasis of the work on fumigants has continued to be given to the treatment of bulk grain. A series of small-scale field trials were planned early in the year but it proved unusually difficult to find bulks of grain suitable for the tests and the amount of such field work completed has been less than in recent years. Meanwhile there has been some further examination in the laboratory of methods of determining concentrations of certain chlorinated and brominated hydrocarbons singly and in mixtures.

Discussions have continued on the provision of gas-circulating plants in certain silos. It is expected that faster progress will be made with these schemes as a result of the information which has been collected by Mr. Burns Brown and Mr. Heseltine during their visit to Switzerland in September. More than forty of the silos in Switzerland are fitted for gas circulation, and a valuable body of experience of this method of fumigation exists there.

A considerable amount of time has been given to bringing into full operation two new air-conditioned rooms at 10 and 15°C. and 70 per cent R. H., each containing a specially designed fumigation chamber (Plates II and III). Each room has bench space and storage space for test insects. This is an ideal arrangement for toxicity tests as the preparation of samples of test insects and their examination after exposure is carried out in the room in which they are fumigated. Variability of results arising from failure to maintain constant conditions throughout the test is thus reduced to a minimum. The arrangement of these rooms also facilitates other types of investigation on fumigants. Each chamber is of about 1,700 litres capacity and is designed to withstand vacuum. The gas can be stirred by a variable speed fan with a vacuum tight bearing mounted in the dished end or by circulating through the 1½-in. bore glass pipe-line connecting top and bottom of the chamber. A connection from this pipeline to the outside of the building allows the gas to be removed at the end of an experiment. A sight window and internal lighting is provided. For tests of toxicity to insects the desired concentration of fumigant is established in the chamber and wire gauze cages containing the samples of insects can then be introduced along the light alloy channels shown in Plate II.

One of these chambers has also been used for a series of tests using different techniques of "vacuum fumigation".

TOXICITY OF FUMIGANTS TO INSECTS

The method described in the Annual Report for 1948 has been continued. Tests are carried out simultaneously on different species of test insect by exposing all the samples in a large fumigation chamber from which they may be separately withdrawn at appropriate intervals to obtain data for exposure time-mortality

regression lines. During the year insect stocks and equipment have been bu up to the level of requirements of the considerably larger tests allowed by t new facilities at 10 °C. and 15 °C. described above.

A series of tests has been started on the relative toxicity of different fumigan including certain chlorohydrocarbons at present being tested as possib fumigants for bulk grain, namely, carbon tetrachloride, ethylene dichlori (1, 2–dichloroethane), tetrachloroethylene (perchlorethylene) and trichlor ethylene. The tests are being made at intervals of several weeks and in each t toxicity of one fumigant is tested at 10, 15, and 25 °C. About ten types of te insect are used so that the results may be independent of the particular su ceptibility of any one species or stage. By obtaining data on different fum gants it has been possible to make a wider approach to the problem of the effe on resistance of physical conditions at the time of fumigation. To assess t practical value of a particular fumigant in different types of treatment the to icity data must be considered together with the available information on t chemical and physical behaviour of the compound.

Six samples of each type of test insect are fumigated at each temperatu and estimates of dosage for 99·9 per cent kill made by fitting a regression li by eye to the data. The accuracy of these estimates is limited by the sma amount of information on which each is based, but for the comparative purpos of these tests in which only very large differences are considered the errors a relatively unimportant. Specific instances of high resistance which are particular practical importance have been noted for more detailed study.

Among the test insects a balance is being maintained between adult an pre-adult stages and while the choice of species has been determined mainly b their economic importance they vary as much as possible in food requiremen and limiting temperatures.

The following insects are being used in the current tests:—

Calandra granaria and *Calandra oryzae*—adults and pre-adult stages.
Tribolium confusum—adults and pupae.
Tribolium castaneum—adults.
Oryzaephilus surinamensis—adults.
Ptinus tectus—adults and cocoons.
Rhizopertha dominica—adults.
Laemophloeus minutus—cocoons.
Trogoderma granarium—larvae.

A routine method of culturing *Tenebrio molitor* larvae was worked out, but s far it has only been possible to test small samples at 15 °C.

In practice, foodstuffs fumigated at a low temperature may be expected t remain at or near that temperature for some time afterwards and in the prese series of tests adult insects fumigated at, say 10 °C. were kept at that temperatu during the observation period. In the tests with chlorohydrocarbons und these conditions the adult insects did not show the marked increase in resistan on decrease of temperature from 15 to 10 °C. which has been reported by oth workers studying the effect of temperature on the toxicity of fumigants. Ve few data have been published relating to the chlorohydrocarbons but it is pr bable that in most previous work at low temperatures on these and oth fumigants the insects have been moved after fumigation to a common high temperature for observation.

If the insects are kept at 10 or 15 °C. after fumigation with chlorohydrocarbons as in the present tests then in most cases the mortality increases over a very long time and the dose estimated for a complete kill shows a corresponding decrease. The following estimated dosages of carbon tetrachloride (in mg. hr per litre) for 99·9 per cent kill of *C. granaria* adults illustrate this point.

Days after fumigation	Temperature 10 °C.	15 °C.	25 °C.
7	18,600	15,000	3,000
13	16,600	8,300	3,000
25	10,500	6,900	3,000
42	7,400	6,600	3,000
55	6,900	6,600	—
69	6,900	6,600	—

The effect of moving the insects after fumigation to a higher temperature has been shown by fumigating *C. granaria* adults with ethylene dichloride at 10 °C. and subsequently keeping half at 10 °C. and half at 25 °C. The insects held at 25 °C. showed no increase in mortality after 10 days and would have required a concentration-time product of 4,300 mg. hr. per litre to produce 99·9 per cent mortality, while those at 10 °C. died progressively over a period of six weeks and would have required a c.t. product of less than 1,400 to produce the same mortality at the end of this period. (A subsequent test showed that with a lower initial dosage and allowing a somewhat longer period of observation, the c.t. product for 99·9 per cent kill of *C. granaria* adults held at 10 °C. could be reduced as low as 350 mg. hr per litre).

At 25 °C. pre-adult stages were more resistant than adults of the same species. The consistently high relative resistance of pre-adult stages of *C. granaria* to the chlorinated hydrocarbons and the importance of this species as a pest of grain makes their resistance a critical factor in considering the relative toxicity of fumigants of this type. They present certain difficulties as a test insect because they remain inside the grain during the whole course of their development. Mortality data were obtained by exposing samples of infested grain and recording numbers of emerging adults. Their rate of mortality after fumigation could not be measured. 10 °C. is just below their developmental minimum and at 15 °C. development takes several months. In these tests samples of infested grain fumigated at 10 °C. were taken to 15 °C. a few days after exposure and finally returned to 25 °C. to complete development.

The results suggest that at 10 °C. very high dosages would be required to kill all stages of this species within a short time after fumigation, but that these could be very much reduced by the certainty of the prolonged continuation of the low temperature when dosage could be based on final mortality. The interaction of resistance to cold and resistance to fumigation is being investigated by making more detailed comparative tests between *C. granaria* and *P. tectus*, a beetle which will complete its life cycle at 10 °C. Tests have been made on the resistance of pre-adult stages of laboratory stocks of *T. confusum* and *O. surinamensis* to 10 and 15 °C. and of *C. granaria* to 10 °C. It is hoped to compare them with wild stocks in this respect.

The following table provides an indication of the amount of variation of resistance found. It shows preliminary estimates of dosage (mg. hr per litre)

for 99·9 per cent kill (based on final examinations of the samples) in tests mad at 15°C.

	C_2Cl_4	$C_2H_4Cl_2$	C_2HCl_3	CCl_4
Tribolium castaneum, adults	400	1,300	700	2,500
Tribolium confusum, adults	1,000	< 100	2,500	5,500
Ptinus tectus, adults	1,200	< 100	2,000	2,500
Calandra granaria, adults	2,000	2,300	5,500	6,600
Calandra granaria pre-adult stages	4,000	6,600	12,500	23,000

There are some striking variations in the order of susceptibility betwee species but in very general terms it can be said that the fumigants have bee placed in the table in order of decreasing toxicity from tetrachloroethylene t carbon tetrachloride. (*W. Burns Brown, Miss E. M. Reynolds, Miss B. D. Hole Miss M. F. East, S. G. Heuser, R. B. Hedley, Miss C. E. Thomas*).

ANALYSIS OF HALOGEN DERIVATIVES OF METHANE, ETHANE, AND ETHYLENE

Methods for the determination of concentrations of certain fumigants whic are now in use or which are likely to be used in field trials have been examined The methods of Winteringham (*J. Soc. chem. Ind.*, 1942, **61**, 186–190) for th determination of carbon tetrachloride, ethylene dichloride, 1, 2–dichloroethylen (commercial mixture of approximately 60 per cent *cis* and 40 per cent *tran* isomers), trichloroethylene and tetrachloroethylene have, with slight modi fication, including electrometric titration of the chloride, been found suitabl for use in field tests. In addition, the modified method has been applied to th determination of ethylene dibromide and bis-beta-chloroethyl ether.

A method has been developed for the determination of mixtures of carbo tetrachloride and ethylene dibromide in air. Duplicate samples are taken b the usual evacuated flask technique, one flask containing monoethanolamin and the other 5 per cent alcoholic potash. The first sample is treated as in th usual method for carbon tetrachloride and gives a recovery of 100 per cen ethylene dibromide and 97 per cent carbon tetrachloride. The second sample diluted, neutralized and the bromide present oxidised to bromate and determine iodometrically by a modification of the Kolthoff-Yutzy method. Under thes conditions 50 per cent of the bromide is determined—

$$CH_2\,Br.\,CH_2\,Br. + KOH = CH_2 : CH\,Br. + K\,Br. + H_2O$$

(*H. K. Heseltine, G. A. Hamilton, J. B. Waller*

FURTHER TESTS OF COMPOUNDS AS FUMIGANTS FOR BULK GRAIN

Considerable tonnages of grain are now treated in this country in silo bins wit carbon tetrachloride. Mixtures of ethylene dichloride and carbon tetrachlori

re used for the treatment of small bulks of grain on floors as well as for other urposes. When the severe shortage of sulphur made the continued availability f carbon tetrachloride for fumigation purposes problematical a series of tests as started to find a substitute for use in treating bulk grain. Preliminary tests ave been carried out in the manner described in the Reports for 1949 and 1950 y spraying small areas of the surface of large bulks and studying the behaviour of ach fumigant by measuring concentrations at different depths. 1, 2–di-hloroethylene (commercial mixture of isomers), trichloroethylene and tetra-hloroethylene (perchloroethylene) have been tested in comparison with carbon etrachloride, and, in addition, two mixtures of carbon tetrachloride and ethylene ibromide were included in the series. The speed and degree of penetration f these fumigants into a bulk of grain after application to the surface varies onsiderably and appears to be related to the rate of evaporation of each com-ound as determined in simple laboratory experiments. The mixed 1,2–di-hloroethylenes had a speed of penetration of the same order as that of carbon etrachloride. Trichloroethylene penetrates more slowly but is better in this espect than ethylene dichloride. Tetrachloroethylene has the lowest speed of enetration of these compounds. Considering these results in conjunction with vidence on the general levels of toxicity of the compounds to insects it appears hat, in general, the order of increasing toxicity is the reverse of the order of ncreasing ability to penetrate through bulks of grain. Judging from published ata it appears that the mixture of 1, 2–dichloroethylenes, the only fumigant mong those tested which resembles carbon tetrachloride in its behaviour in ulk grain, has too low a toxicity to be an effective substitute. The results uggest, however, that trichloroethylene might be used alone for the treatment of oderate depths of grain on floors. Tetrachloroethylene might replace thylene dichloride for certain purposes.

Ethylene dibromide tends to remain near the surface to a much greater extent han ethylene dichloride when applied in admixture with carbon tetrachloride.)wing to its high toxicity and its tendency to maintain high concentrations at or ear the surface for long periods it appears that mixtures with carbon tetra-hloride could be used with success for the fumigation of floor-stored grain.

It is proposed to extend tests with some of these fumigants to grain in silo ins.

The complete fumigation of a single very large bulk of floor-stored grain con-isting of several thousand tons presents a very difficult problem. Experience ained over the past two years in the treatment of small areas of grain by surface pplication of carbon tetrachloride, ethylene dichloride and mixtures of these ompounds suggests that it should be possible to extend the method to the umigation of the whole bulk. A report from the U.S.A. (Cotton, R. T., *Pest Control*, 1950, **18**, 10) indicates that the operational difficulties of applying the arge quantities of fumigant necessary can be overcome. As a preliminary to a ull scale trial a test has been made in collaboration with the Infestation Control Division of The Ministry of Agriculture and Fisheries in which the effect of reating a larger area than in previous tests was studied. In a large bulk areas of 25 feet square and 5 feet square were selected, and were both treated with arbon tetrachloride at the same dose per unit area. The fumigant was applied o the larger area by means of an electrically driven self-priming pump and engths of rubber hose. Concentrations were measured at points inside and outside the treated areas. Over a 7 day period fumigant concentrations were

maintained at a higher level in the larger area. The spread of fumigant to poin outside this area was also greater than from the smaller area. (*H. K. Hese tine, S. G. Heuser, G. A. Hamilton, J. B. Waller*).

STUDY OF "VACUUM FUMIGATION" TECHNIQUES

A number of tests have been carried out to compare the efficiencies of variou methods of fumigation at reduced pressure with treatment at atmospheri pressure.

The new chamber at 15 °C. has been used for the majority of these tests i which the behaviour of the fumigant has been studied by determining gas co centrations in the free space and at different depths within the product. Th fumigant used was methyl bromide and the products tested included bagge wheat, bagged decorticated groundnuts, boxed dates and bagged wheatfee A technique of drawing gas samples in completely evacuated flasks was use for determining concentrations when the chamber was at a reduced pressur Preliminary results indicate that for granular products such as wheat or groun nuts penetration under the conditions of a treatment at atmospheric pressu is so rapid that there is little advantage in employing "vacuum" technique Penetration into a box containing a compressed block of dates can be extreme slow at atmosphere pressure and it is with products of this type that treatment reduced pressure shows an advantage. Experimental work using boxes of dat is made difficult by the impossibility of obtaining reproducible results from bo to box due to variations in packing. Further tests are being made using bagge wheatfeed as the product. The tests so far completed show that the techniq in which the fumigant alone is introduced to the "evacuated" chamber and th "vacuum" sustained for a period is more efficient in promoting penetration tha the technique in which a mixture of air and fumigant is introduced to th "evacuated" chamber until the pressure approaches atmospheric. It should b possible to improve the efficiency of the former process by "breaking th vacuum" some time before the end of the treatment. (*W. Burns Brown, S. G Heuser, R. B. Hedley, Miss C. E. Thomas*).

FUMIGATION OF DRIED FRUITS IN TINS

Some further tests have been made on the disinfestation of dried fruits packe by the Admiralty in tins which are sealed by soldering before despatch t depots overseas. Two promising methods of applying fumigants at the time o packing were described in the Report for 1950. Further tests on tins containin 30 lb. of currants were made at 25 °C. using dosages of 1 ml. and 2 ml. of ethylen dichloride and at 15 °C. using dosages of 2 ml. and 3 ml. The lower dose a each temperature was completely effective in a period of 17 days in killing th following insects and mites:—

Ephestia elutella, larvae.
Oryzaephilus surinamensis, adults and larvae.
Tyroglyphus farinae, *Tyrophagus* sp. and *Tyrolichus casei*.
Carpoglyphus lactis (tested at 15 °C. only).
Glycyphagus sp. (tested at 15 °C. only; no hypopi were present).

In controls at both temperatures insects and mites were active at the end of th test period.

In connection with the alternative treatment using carbon dioxide, e ments at 15 °C. and about 73 per cent R. H. have shown that the mites ı above can survive exposure for 18 days to a concentration of about 50 per cent of carbon dioxide in air. Further tests were not made since the simpler method using ethylene dichloride appeared to be satisfactory. (*W. Burns Brown, M. E. Solomon, A. M. Cunnington, and Miss E. M. Reynolds*).

BIOCHEMISTRY

Mr. Winteringham was awarded a Commonwealth Fund Fellowship and is working at the University of California, with Professor Hoskins. In his absence Mr. Lewis is in charge of the work of the Section.

METHYL BROMIDE RESIDUES IN WHEAT

In order to study the methylated compounds produced in wheat proteins as a result of fumigation with methyl bromide several methods have been considered. The method of Stein and Moore (*J. Biol. Chem.* 1948, 1949) for the separation of amino acids on columns of potato starch has been applied to wheat gluten hydrolysates with successful results. The individual amino acids can be completely separated, and the method enables larger amounts to be used than with filter paper chromatography.

The eluent from the column is collected in 1 gram fractions, and a technique has now been worked out for the concentration and application of the fractions to lead backed filter discs, prior to counting. It is intended to apply this method to the examination of a hydrolysate of wheat gluten which has been exposed to C^{14}-labelled methyl bromide. (*R. G. Bridges*).

FORMATION OF VOLATILE SULPHUR COMPOUNDS IN WHEAT FUMIGATED WITH METHYL BROMIDE

The objectionable taint observed in wheat flour after fumigation with methyl bromide has been attributed to the formation of dimethyl sulphide, produced by the decomposition of sulphonium salts resulting from the methylation of methionine residues. In order to confirm the presence of volatile sulphur compounds in fumigated wheat flour, wheat has been used in which all the sulphur compounds were labelled with S^{35} by growing in a nutrient solution containing labelled sulphate.

A sample of this wheat was milled and exposed to methyl bromide for 48 hours. Free methyl bromide was removed by airing for 48 hours. The flour was then placed in a closed vessel at a low humidity for one week, and then aired through an electric furnace in order to oxidize volatile sulphur compounds to sulphate, which was precipitated as the barium salt. The S^{35} present in the barium sulphate was then measured in an internal flow G. M. counter.

Storage at low humidity produced 0·117 p.p.m. of volatile sulphur, and further storage at a high humidity produced 0·32 p.p.m. These amounts are equivalent to 0·235 and 0·62 p.p.m. of dimethyl sulphide.

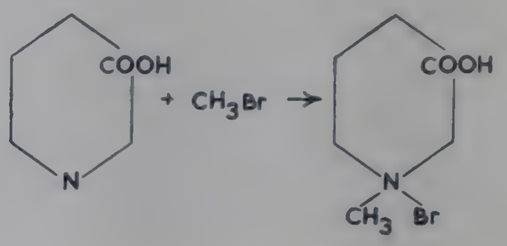
Although the amounts are small compared with the total methyl bromide residue they are sufficient to account for the taint observed. (*R. G. Bridges*).

ACTION OF METHYL BROMIDE ON NICOTINIC ACID

It has been suggested that methyl bromide may impair the nutritional value of foodstuffs by reacting with the vitamins. A series of tests has therefore been

carried out in collaboration with the Dunn Nutritional Laboratory at Cambridge to determine whether methyl bromide treatment has any adverse effect on some vitamins of the B group.

When aqueous solutions of nicotinic acid and nicotinamide were exposed to high concentrations of methyl bromide some methylation was shown to occur.



Further tests were then carried out on milled wheat at a range of moisture contents from 12 to 15·5 per cent and on whole wheat groundnuts, barley, peas and maize. Nicotinic acid was estimated by chemical and microbiological methods in controls and in samples treated with methyl bromide at concentration time products up to 2,500 mg. hr per litre, but no reduction in nicotinic acid content could be detected.

Further tests are in progress on the vitamin B content of foodstuffs treated with methyl bromide. Preliminary tests with ground grain have failed to show any reduction of B^1 or riboflavin. (*S. E. Lewis*).

USE OF YEAST TO DETERMINE THE ACTION OF SOME INSECTICIDES ON CELLULAR METABOLISM

Preliminary work had shown (Plate IV(A)) that the aerobic and anaerobic metabolism of yeast cells could be inhibited by methyl bromide. A more detailed investigation of metabolism has now been carried out to determine which of the enzymes involved are inhibited by this insecticide. Parallel tests have been carried out to determine the effect on rate of cell division and viability of individual cells.

The rate of cell division was determined by measuring the increase in light absorption due to the increase in the number of cells, by means of a photo-electric absorptiometer, the cells being exposed to methyl bromide in a closed vessel.

The rate of cell division is conveniently expressed in terms of "generation time" (time required to double the cell number), and some typical examples, showing the effects of methyl bromide, are given below:—

Concentration of Methyl Bromide	*Generation Time*
0	2·8 hours
$0{\cdot}5 \times 10^{-3}$ Molar	3·5 ,,
$1{\cdot}9 \times 10^{-3}$,,	12 ,,
$4{\cdot}9 \times 10^{-3}$,,	(No cell division)

A reduction in oxygen uptake of 40 per cent has been found in cells exposed to 3×10^{-3} molar methyl bromide under similar conditions.

Viability tests were then carried out to show whether a proportion of the cells were killed by these concentrations or whether the metabolism of all the

cells was temporarily inhibited. The tests were made by treating cells in phosphate buffer, in order to prevent cell division, and then progressively diluting the suspension to a concentration of about 100 cells/ml. 1 ml. of this suspension was then incubated on nutrient agar plates for two or three days, or until no further colonies appeared. With an exposure of 5 hr, 2×10^{-3} molar methyl bromide caused no kill, whereas double this dose caused 100 per cent kill.

Earlier observations had led to the conclusion that one or more of the intermediate metabolites accumulate in treated yeast suspensions. One substance has now been identified as acetaldehyde by isolation of the crystalline dimedone derivative, and has been found to accumulate under both aerobic and anaerobic conditions. The accumulation of acetaldehyde suggests that the enzyme alcohol dehydrogenase may be inhibited, and this has been confirmed by measuring the alcohol dehydrogenase activity of treated cell-free extracts.

The fact that methyl bromide can react with nicotinic acid in aqueous solutions suggests that it may also react with coenzymes I and II and thereby inhibit their activity. No evidence of inhibition of the coenzyme fraction of yeast was obtained however when treated with concentrations of methyl bromide which produced a considerable inhibition of the apozymase fraction.

A decrease in the rate of phosphorylation of glucose by dried yeast, treated with methyl bromide, together with evidence provided by other workers suggested that the enzyme hexokinase may also be inhibited:—

$$\text{Glucose} + \text{Adenosine triphosphate} \xrightarrow{\textit{Hexokinase}} \text{Glucose-6-Phosphate} + \text{Adenosine diphosphate}$$

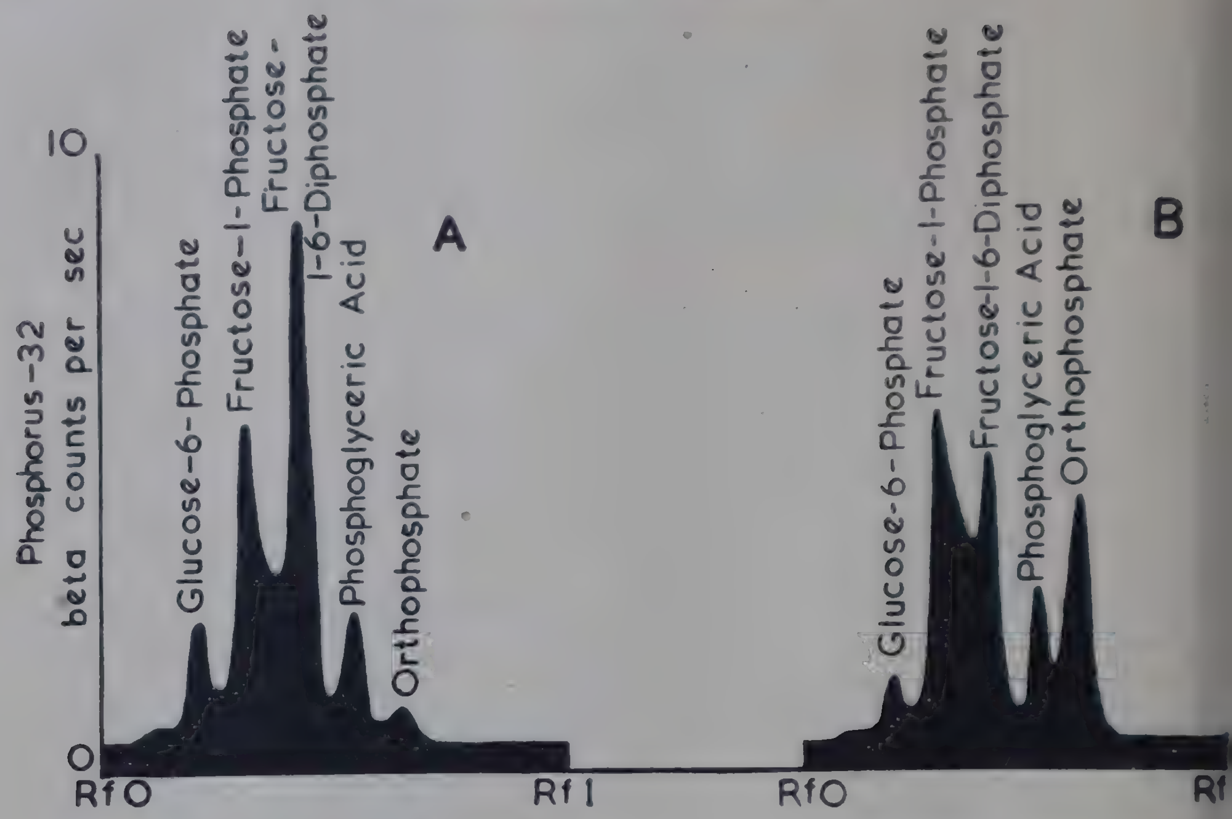
Further evidence of the inhibition of hexokinase has now been obtained by using radioactive phosphate to study the formation of phosphate esters during the utilisation of glucose by a cell free yeast extract. After exposure to methyl bromide the extract was incubated with P^{32} labelled phosphate and glucose. The phosphate compounds were then extracted and separated on a paper chromatogram. The position and quantity of each phosphate ester was then determined by passing the paper chromatogram under a G. M. counter in a scanning apparatus devised and constructed at the Laboratory (Plate IV(B)) By comparing a record of the activity obtained from the treated sample with that of the control (Fig. 2) it will be seen that the phosphate uptake has been reduced, and that glucose-6-phosphate and fructose 1 : 6-diphosphate are also reduced. Such a result could be accounted for by a shortage of adenosine triphosphate, and this point is being investigated.

These experiments suggest that the action of methyl bromide on yeast may be accounted for by the reduction in carbohydrate metabolism, resulting from the inhibition of at least two enzyme systems, and the consequent accumulation of metabolites such as acetaldehyde. (*S. E. Lewis, Miss E. G. Halls*).

PREPARATION OF THE GAMMA ISOMER OF BENZENE HEXACHLORIDE

A series of experiments have been planned to study the biochemistry of the gamma isomer of benzene hexachloride (BHC), in insects and in treated foodstuffs, using radioactive gamma-BHC.

It was first necessary to devise a simple method to separate the gamma isomer from a prepared mixture and estimate the amount present. A chromatographic



A—Contact
B—Treated with methyl bromide

FIG. 2.—*Radio-chromatograms of yeast extracts containing Phosphorus* 32

method using strips of filter paper saturated with acetic anhydride, based o method described by Moynihan and O'Colla (*Chem.* & *Ind.*, 1951) has be found satisfactory. The following method has been introduced to identify positions of the isomers on the chromatogram. The strips are first sprayed w monoethanolamine solution, and the chloride is then detected by spraying w acid silver nitrate. On exposure to ultra violet light the positions of the isom are represented by blue spots or bands. The intensity of the colour gives approximate estimate of the quantity of each isomer present.

This method has been used to estimate the gamma-BHC in samples of mi isomers prepared on the micro scale by chlorination of benzene in methyl chloride solution in the presence of the ultra violet light. Samples of BHC h now been prepared which are believed to contain about 20 per cent of the gam isomer.

Attempts to separate the gamma isomer on a larger scale using partit chromatography on a silica gel column have produced encouraging resu An apparatus has been designed for the preparation of radioactive BHC on micro scale. Cl^{36}-labelled chlorine is produced by electrolysis of a Cl^{36}-labe chloride solution and is then circulated through a solution of benzene in met ene chloride in an enclosed system. Trial runs with this apparatus are now progress. (*A. Harrison*).

METABOLISM OF DDT BY SUSCEPTIBLE AND RESISTANT HOUSEFLIES

Metabolism and penetration studies using the radioactive bromine analo of DDT, have been continued along the lines described in the 1950 An Report, and a detailed account of this work will be published shortly.

y using a sample of radioactive bromo-DDT of high specific activity it has v been possible to isolate the ethylene derivative of bromo-DDT from ceptible flies which have received a median lethal application of bromo-DDT. s means that the ability to dehydrohalogenate DDT is not a unique character- c of the resistant flies, and may be more apparent in these strains only because their ability to tolerate a high concentration of the insecticide for a longer iod.

n order to investigate the importance of dehydrohalogenation as a defence chanism in resistant flies tests are being carried out using bromo-DDT and itropropane derivative of DDT which cannot be dehydrohalogenated. Two istant strains of fly, originating from Italy and Sardinia respectively are ng compared with the normal susceptible laboratory strain. Preliminary icity tests made by applying 1 μl. of an acetone solution of the insecticide to thorax of individual flies have shown that the Italian strain is less resistant the nitropropane derivative than to bromo-DDT. Further tests are being ried out to establish whether the Sardinian strain behaves similarly, and ether differences in the rate of penetration of the nitropropane derivative d bromo-DDT are contributory causes. (*Miss P. M. Loveday, H. Harrison*).

ST INFESTATION LABORATORY,
London Road,
Slough, Bucks.

G. V. B. HERFORD,
Director of Pest Infestation Research

arch, 1952.

APPENDIX I

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APPENDIX II

Staff of the Pest Infestation Laboratory 1951

Director of Pest Infestation Research—G. V. B. Herford, O.B.E., M.Sc.

Senior Principal Scientific Officer (Assistant Director)—E. A. Parkin, Ph.D. M.Sc., D.I.C.

Principal Scientific Officers—W. B. Brown, M.Sc., F.R.I.C., A.R.C.S., D.I.C. T. A. Oxley, B.Sc., A.R.C.S.; M. E. Solomon, M.Sc.; F. P. W. Winteringham, F.R.I.C.

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Scientific Officers—C. W. Coombs, M.Sc.; *Mrs. H. B. Hollier, M.Sc.; Mrs P. J. Maycock, B.Sc.; G. E. Woodroffe.

Senior Experimental Officer—A. A. Green.

Experimental Officers—A. M. Cunnington; K. S. Fowler, B.Sc., A.R.I.C. A. Harrison; H. K. Heseltine, B.Sc.; S. G. Heuser; Miss E. M. Reynolds Miss H. C. N. Turnbull, M.A.

Assistant Experimental Officers—G. Ayerst; Mrs. G. Blake, B.Sc.; G. T. Bills B.Sc.; R. G. Bridges; H. D. Burges; Miss M. A. Cant, B.Sc.; *Mis B. Edwardes-Evans, B.A.; *Miss W. M. Eustace; K. G. Gostick; G. A Hamilton; Miss B. G. Halls, B.Sc.; J. G. Harvey; R. B. Hedley, B.Sc. J. P. Heslop; Miss B. D. Hole; Miss K. D. Lambe, B.Sc.; Miss J. R. Long Miss P. M. Loveday, B.Sc.; Miss S. G. Rawle, B.Sc.; *Miss P. L. Robertson, M.Sc.; A. M. Simmonds; Miss M. K. Winckler.

Senior Assistant (Scientific)—A. E. Broughton (Glass blower).

Assistants (Scientific)—Miss B. E. Adamson; Miss C. Belcher; Miss D. C Blackman; Miss R. Borrett; D. Budd; *Miss B. Clayton; Miss J. C Currie; Miss M. F. East; Miss P. M. Heaton; G. C. Hellyer; Miss M Jackson; Miss M. J. Kane; *Miss E. A. Myerscough; Miss S. M Nightingale; B. J. Southgate; K. I. Street; Miss C. E. Thomas; P. S Tyler; J. B. Waller; *Miss S. R. Wiley.

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Instrument Maker—W. Cordaroy.

Carpenter—J. Gray.

Store Keeper—E. A. Wiggins.

Driver—R. Bateson.

Gardeners—A. O. Moss; A. W. Mills.

Cleaners—Mrs. M. Williams (Caretaker); Mrs. Waters; Mrs. Day.

Labourer—C. G. Tubb.

*Resigned in 1951.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

REPORT OF THE PEST INFESTATION RESEARCH BOARD

WITH THE REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH

FOR THE YEAR 1952

LONDON: HER MAJESTY'S STATIONERY OFFICE
1953

PEST INFESTATION RESEARCH BOARD

31st December, 1952.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH,
Charles House, 5-11, Regent Street,
London, S.W.1.

* Resigned during 1952.

CONTENTS

REPORT OF THE PEST INFESTATION RESEARCH BOARD FOR THE YEAR 1952

To the Lords of the Committee of the Privy Council for Scientific and Industrial Research.

MAY IT PLEASE YOUR LORDSHIPS,

WE, the Pest Infestation Research Board, beg leave to present a report on our proceedings during the year 1952. The Report of the Director of Pest Infestation Research for the same period is appended.

Sir John Simonsen retired from the Chairmanship of the Board on the 31st March, 1952, on completion of his term of office. We should like to place on record our warm appreciation of Sir John Simonsen's guidance in the conduct of our business during his period of office. We have welcomed your Lordships' appointment of Mr. F. R. Horne, the Director of the National Institute for Agricultural Botany to be Chairman in place of Sir John Simonsen.

During the year there have been the following changes in the Assessors to the Board. Dr. I. Thomas has replaced Mr. C. T. Gimingham as the representative of the Ministry of Agriculture and Fisheries; Lt. Col. Pasricha has replaced Dr. Krishna, representing the Government of India; and Mr. G. R. Bates, who represented Southern Rhodesia, has retired, but a successor has not yet been appointed. We should like to express especially our appreciation of the services which Mr. Gimingham has given to our work. He has acted as Assessor for the Ministry of Agriculture and Fisheries to the Board during the whole of its life, and also to its predecessor the Pest Infestation Research Committee. He was also a member of the Grain Infestation Survey Committee, set up in 1937, whose work led to the establishment of the Pest Infestation Laboratory.

We have held three meetings during the past year, including one at the Laboratory, where we were able to inspect the research work in progress.

RESEARCH PROGRAMME

An important development during this year has been the improved liaison with Colonial Territories. A valuable link already existed through the Director's Chairmanship of the Stored Products Research Sub-Committee of the Committee for Colonial Agricultural, Animal Health and Forestry Research, of which Committee also he is a member; and through his membership of the Colonial Insecticides Committee. Further development, however, has been made possible by the work of the Colonial Liaison Officer, Mr. D. W. Hall, to whose appointment we referred in our Report for 1951. Mr. Hall has already made two tours, one to East Africa, and the other to the Central and West African Territories, which was extended by invitation to include a short visit to South Africa. In the course of these visits, Mr. Hall was able to discuss a number of problems and frequently to offer immediate advice based on

experience gained at the Laboratory. On many other problems, however, the Laboratory can only provide answers after appropriate research has been conducted.

In addition, Mr. Oxley has visited Malaya, where at the request of that Government he studied and advised on problems of rice storage.

The closer contact with the Colonies and with Colonial problems represents a stimulating and valuable development in the life of the Laboratory. It is therefore a matter of some concern to us that the Laboratory is not able to give as much attention to these problems as they merit. Taken together they would represent a considerable increase in the Laboratory's work, but their solution would be of importance both to Colonial development and to the United Kingdom.

A detailed account of current research is given in the Director's Report. We wish here to draw attention to some features of special interest.

STORAGE OF GRAIN UNDER AIR-TIGHT CONDITIONS

It has long been known that insects infesting grain may be killed if the grain is stored under air-tight conditions, but it has usually been stipulated that grain intended for such storage should have a low moisture content.

The conditions of air-tight storage in France were inspected during the year by Mr. Oxley and Miss Hyde, accompanied by Mr. Pasfield of the Ministry of Agriculture and Fisheries. Recently, in France, grain of relatively high moisture content has been successfully stored for several months in air-tight silos. This development has been made largely on an empirical basis without an adequate background of scientific knowledge concerning the physiological responses of normally damp grain and of its associated micro-organisms of conditions of anaerobic storage.

If successful, this method would be of considerable importance in Britain, since it would make it possible for grain of high moisture content as normally harvested by combine in this country, to be stored in safety, thus postponing or even obviating the need for drying. The Laboratory is therefore making a detailed scientific investigation of the method. Work has begun on a laboratory scale and will be extended to a semi-commercial scale during the coming year.

CHEMICAL INVESTIGATION OF CONTACT INSECTICIDES

An important part of the research programme of the Laboratory is concerned with the use of contact insecticides and with their assay in very small quantities by biological and chemical methods.

A considerable amount of work has been undertaken, in collaboration with other Laboratories, in order to improve existing methods for the chemical analysis of certain of these insecticides. In particular, attention has been directed to the chemistry of the pyrethrins and related compounds, with a view to developing a method for their chemical estimation which would agree more closely with the results obtained by biological assay techniques.

CONTROL OF BLOWFLIES

It was reported last year that experiments had been undertaken on the control of blowflies at a railway sidings in North London, where domestic refuse is collected and sorted. It was estimated that at the peak period there were some

25,000,000 blowfly larvae in 15,000 sq. ft. of ground covered by sidings, and that over 100,000 flies emerged from this area each day. As a result of trials with various insecticidal treatments applied to the ground, it has been found that an application twice a week of a 5 per cent DDT dust gave a control of more than 99 per cent.

Recommendations for such applications of DDT dust were made to the authorities concerned, as a result of these experiments, and for a total cost of about £100, emergence of flies from this area has been virtually prevented during 1952.

It was not known, however, whether blowflies emerging from places where there was an abundance of suitable foodstuff would stay in the immediate neighbourhood or would migrate further afield. Accordingly some 30,000 blowflies which had been previously fed, for purposes of identification, on water containing a radioactive phosphorus salt were released at the refuse sorting depot mentioned. A large number of traps were distributed at points up to two miles distant from the centre, and the flies caught in the traps were examined. Labelled flies were found to have dispersed from the centre of liberation and to have visited canteens, hospitals, etc., situated up to two miles away.

In some cases they scattered at the rate of a mile a day.

RESISTANCE OF HOUSEFLIES TO DDT

During the year attention has been paid to filling in certain gaps in our understanding of the resistance of houseflies to DDT. The present state of knowledge in this field can be summarized by saying that this resistance is not due to lack of penetration of the insecticide through the insects' integument; susceptible as well as resistant flies are capable of decomposing absorbed DDT, provided the dose absorbed is sufficiently low. There is evidence of at least two different mechanisms of housefly resistance to DDT, one linked with and the other independent of dehydrohalogenation.

OVERSEAS AND OTHER VISITS

Mr. Winteringham returned to the Laboratory in September, having spent a year in the United States as the holder of a Commonwealth Fund Fellowship. Two terms were spent with Prof. W. M. Hoskins in the Insect Toxicology Laboratory of the University of California at Berkeley. Current research on insecticide biochemistry in the United States and Canada was reviewed by visiting many research institutions in both countries.

Prof. Hoskins came to England in September on sabbatical leave and spent six weeks at the Laboratory, studying the radioactive tracer techniques developed in the Biochemistry Section with a view to their adoption in his own Department in California.

Dr. Parkin, Mr. Winteringham and Mr. Hewlett attended the Third International Congress of Phytopharmacy in Paris in September, and read papers on the application of insecticides at the Section Meetings. Visits were also paid to two Laboratories and to a Department of the French Ministry of Agriculture.

By kind permission of Prof. Keilin, Mr. Lewis is spending a year at the Molteno Institute at Cambridge, undertaking research on enzyme systems.

This experience will be of particular value in furthering the work of the Laboratory on the mode of action of insecticides.

Mr. A. A. Green attended the Health Congress of the Royal Sanitary Institute in April, and read a paper on the Blowfly Problem.

LIAISON WITH OTHER DEPARTMENTS

MINISTRY OF AGRICULTURE AND FISHERIES

Reference is made every year in our Report to the close liaison between the Laboratory and the Infestation Control Division of the Ministry of Agriculture and Fisheries through which many of the results of the Laboratory's work reach application in practice. In that connexion we particularly wish to refer, this year, to the fact that Mr. W. McAuley Gracie, M.B.E., who has been Director of the Division ever since its inception under the Minister of Food in 1942, has now retired from this position. We wish to record our deep appreciation of his work in this field. Mr. Gracie was initially responsible for calling the attention of the food and food handling industries to the significance of infestation, and it is very largely due to his vision and drive that the work on the prevention and control of infestation, now so highly organized, was ever begun.

LIAISON WITH OTHER BODIES, TRAINING, ETC.

The Director is a member of the Fungicide and Insecticide Research Co-ordinating Service of the Agricultural Research Council. Dr. Parkin is a member of the Disinsectization of Aircraft Sub-Committee and the Insecticide Sub-Committee, and Dr. Moore of the Analytical Sub-Committee, all of this Research Co-ordinating Service. Dr. Parkin is also Chairman of the Larval Test Sub-Committee of the Moth and Dermestid Proofing Committee of the Society of Dyers and Colourists and the Textile Institute.

Mr. Oxley represents the Laboratory on a research committee of the British Electrical & Allied Industries Research Association, which is concerned, among other things, with the application of high frequency discharge for the disinfestation of produce.

Mr. Burns Brown is a member of a D.S.I.R. Panel for the Detection of Toxic Gases in Industry.

Advice on technical matters has been given during the year to various Government Departments, including the War Office, Admiralty, Air Ministry, Ministry of Supply, Ministry of Food, Ministry of Works, Ministry of Transport, and to many local authorities.

Visitors to the Laboratory have come from Canada, Australia, Pakistan Ceylon, Nigeria, Gold Coast, Kenya, Uganda, Tanganyika, S. Rhodesia British Guiana, Malaya, Netherlands, Norway, Belgium, U.S.A., Turkey Israel, and Argentina.

We are particularly pleased to record that the Laboratory has been able to assist a number of authorities by providing courses of instruction and training during the past year.

F. R. HORNE,
Chairman

27th January, 1953.

REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH FOR THE YEAR 1952

BIOLOGY

The programme of the Biology Section is at present directed upon several general themes which may be summarized in the questions: Where do infestations come from, and by what means? What physical conditions are required by each species for its survival, and how soon does it die under various unfavourable conditions? What is the rate of development, survival and reproduction, and hence the net rate of increase, of each species under the various conditions in which it is viable? Most of the items of work done in 1952 are identifiable with one or more of these themes.

While the bulk of the year's work has been on projects started before 1952, some new items have been introduced. These include the investigations on *Dermestes frischii*, on the Cigarette beetle (*Lasioderma serricorne*), on the infestation of Durum wheat by mites, on the systematics of *Cryptophagus*, and on the calculation of the rate of population increase. A major item, commenced late in the year, is the investigation of the behaviour and biology of the Khapra beetle, *Trogoderma granarium*.

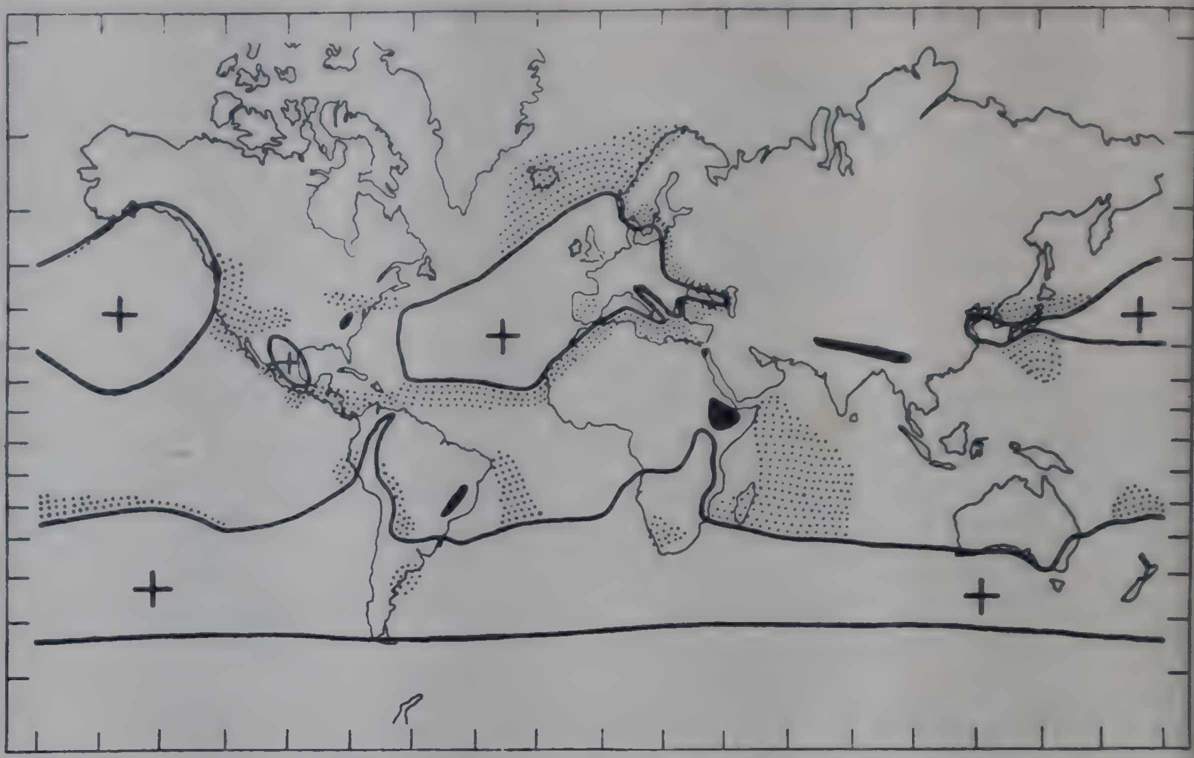
Two major projects have been concluded during the year. The results of a long programme of work on the Spider beetle, *Ptinus tectus*, have been analysed and prepared for publication, and the survey of the fauna of birds' nests has been concluded and an account written.

Owing to the more or less well protected situations in which storage pests live, diurnal fluctuations in temperature and humidity are generally less important than they are to animals living in the open. Laboratory experiments conducted under constant conditions give very useful information, sufficient for many practical needs. However, there is no doubt that much more knowledge of the effects of fluctuating conditions is required at many points. This was emphasized by the difficulty encountered in preparing a world map of the potential distribution of *Ptinus tectus* (Fig. 1), using data on its development under constant conditions.

Some information on the effects of fluctuating conditions is already available from experiments conducted in various uncontrolled sites, for example from the overwintering tests, and also from a few laboratory experiments, including those still in progress on the Varied Carpet beetle (*Anthrenus verbasci*). Such work involves the problem of how to calculate a summary value for the effect upon development etc. of a period of exposure to varying temperatures, and similar problems which are basically physiological.

DISTRIBUTION AND IMPORTATION OF INSECTS

The summarizing of the records of the Infestation Control Division, Ministry of Agriculture and Fisheries, of inspection of cargoes from West Africa has



Areas marked with a + or in black are those in which *P. tectus* can be expected to breed in unheated premises. Stippled areas are probably, and the remaining regions definitely, unsuitable for the development of this species

FIG. 1.—*Potential distribution of the spider beetle*, Ptinus tectus

continued. This survey has shown that the fumigation of groundnuts in Northern Nigeria with methyl bromide has this year been effective in controlling the outbreak of *Trogoderma* which followed the harvesting of a large groundnut crop. Since *Lasioderma* is still present in a very large proportion of cocoa cargoes, work on this species has been started.

The Inspectors of the Division have also continued to send in specimens of *Laemophloeus* for identification. During this year the native outdoor species *L. ater* has been found several times in various kinds of mill. Imported cargoes have yielded one specimen of a new species which had been collected by Mr. D. W. Hall (Colonial Liaison Officer) in several localities in Uganda. A description of this species will be published. (*R. W. Howe*).

RESIDUAL POPULATIONS OF INSECTS

Granary: The analysis of the number and species of insects found in residues in a 5-storey granary has been completed and indicates that there was a close correlation between the type of insect predominating and the quality of the residues. Where there were many whole grains either the Grain weevil, *Calandra granaria*, or the Brown House moth, *Hofmannophila pseudospretella*, dominated the fauna. As the percentage of finely divided material in the residues increased, Spider beetles, *Ptinus spp.*, and the Mealworm, *Tenebrio molitor*, became the dominant insects. As the food value of the residues decreased still further the Fur beetle, *Attagenus pellio*, and the larvae of the Window fly, *Scenopinus fenestralis*, predominated and finally were the only species left.

Rolling stock: Examination of railway vans and wagons during demolition revealed that little infestation of goods was likely from this source. The wagons examined had the floor boards so widely separated that residues were unlikely

to lodge, and since the wagons were open, insects would be subjected to all extremes of weather. No insects were found.

The covered vans had more closely-set floor boards and many had side walls of double thickness enclosing a cavity. No residual food material was found in this cavity and from several vans examined the only insects found were three specimens of the Rust-red Flour beetle, *Tribolium castaneum*, and one of the Brown House moth, *Hofmannophila pseudospretella*.

Ship: A survey of the residual populations in a ship's holds has been made. Samples were taken of residues from those parts of the holds likely to harbour insects and moderate numbers of insects were found. Most of these were connected with the last cargo carried. The cargo had been, in the main, bulk copra and the insects included the Rust-red Flour beetle, *Tribolium castaneum*, the Merchant Grain beetle, *Oryzaephilus mercator*, and the Copra beetle, *Necrobia rufipes*. Other more general pests found were the Black Fungus beetle, *Alphitobius laevigatus*, the Lesser Mealworm, *Alphitobius diaperinus*, and a grain beetle, *Ahasverus advena*. Indications of previous cargoes were found in some samples but the associated insects were all dead; thus in old barley residues dead Grain weevils, *Calandra granaria*, were found. (*C. W. Coombs*).

OVERWINTERING OF STORAGE PESTS

A number of species which failed to survive in unheated buildings in previous winters are being exposed for shorter periods, to find whether some of them could survive if imported late in the winter. The results of work in previous years are being summarized. (*M. E. Solomon*, *Miss B. A. Adamson*).

BEHAVIOUR AND BIOLOGY OF *Trogoderma granarium*

The Khapra beetle tends to penetrate deeply into any available cracks and spaces in the fabric of warehouses and maltings. Larvae are capable of long periods of hibernation in these protected places. This creates a difficult control problem, especially as nothing is known about the movements of *Trogoderma* inside the buildings, and between the building fabric and the various stored foods, in relation to changing physical conditions of the environment.

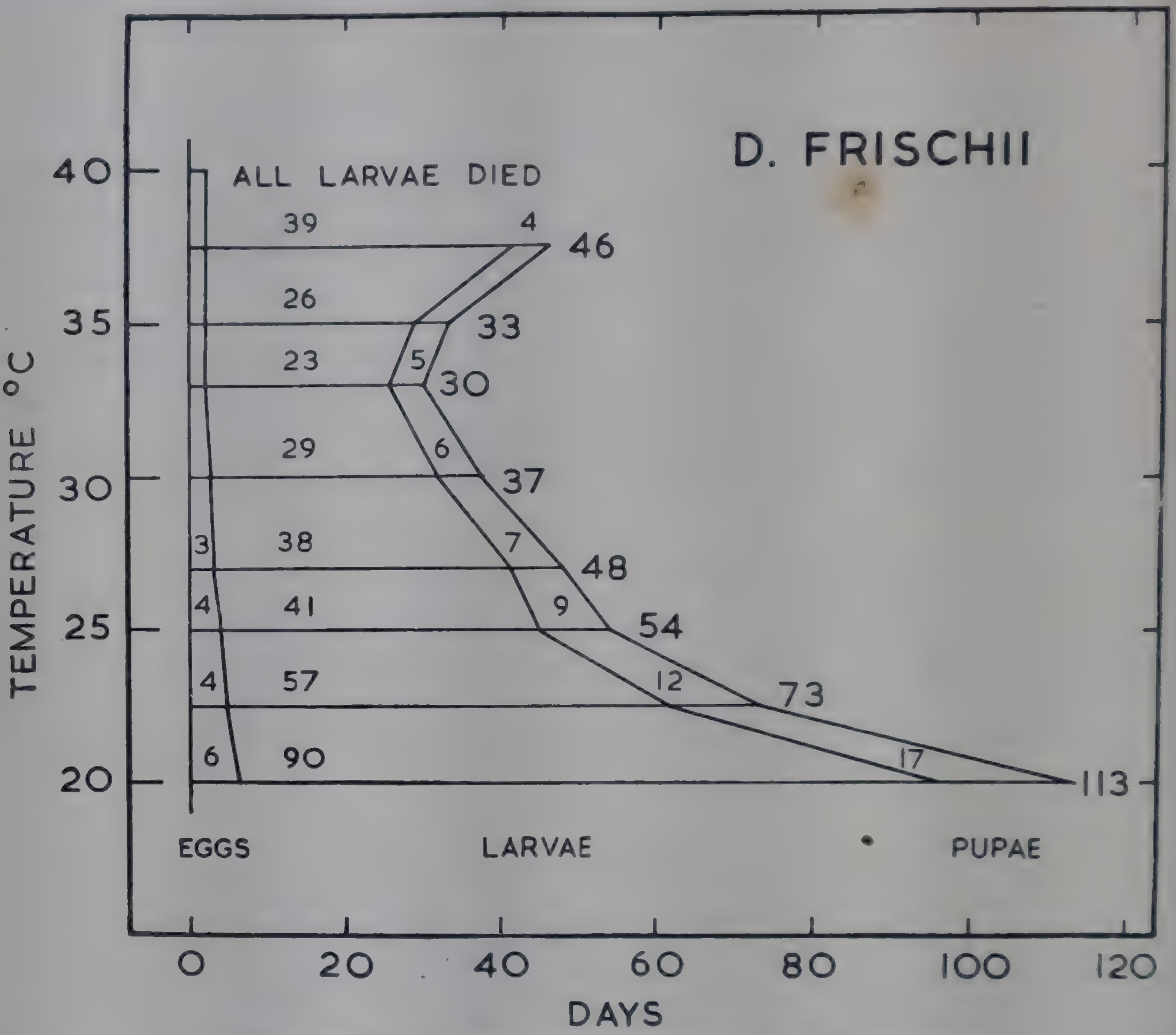
A survey of the environmental conditions in maltings and the distribution of the insect in these buildings has been undertaken. This work, together with a laboratory study, is designed to investigate the behaviour and other aspects of the biology of *T. granarium*. (*H. D. Burges*).

FOOD HABITS AND LIFE HISTORY OF THE CIGARETTE BEETLE

Lasioderma serricorne can feed on a very wide range of foodstuffs, probably wider than that of any other pest of stored food. The susceptibility of a number of West African products to this insect is being tested, since these foods probably facilitate the spread of *Lasioderma* in Nigeria and from one cocoa season to the next. Cowpeas are highly susceptible to attack but locust beans appear to be quite resistant. All work on this species so far has been at 30° and 25°C. It has been bred on wheatfeed at relative humidities down to 25 per cent, which is much below the minimum quoted in the literature. (*R. W. Howe*, *Miss J. E. Currie*).

BIOLOGY OF PTINID BEETLES

The results of the now completed laboratory study of *Ptinus tectus* have been used with meteorological records to map the areas of the world favourable for the species (Fig. 1). This was done by first eliminating areas with mean



All experiments at a constant relative humidity of 70 per cent

FIG. 2.—*The effect of temperature on the length of the developmental stages of the beetle* Dermestes frischii

daily maxima exceeding 31 °C for two consecutive months and also those areas with mean daily minima falling below −4 °C for two consecutive months. Further temperature criteria were applied in a similar way. The zones finally included on the map are probably still a little too wide as it is not possible to predict from the results under constant conditions whether or not the species could really survive the particular variable conditions experienced in some doubtful areas as, for instance, S. Africa. On the other hand, *P. tectus* no doubt occurs indoors in places where outdoor conditions would be fatally cold.

Work with *Mezium affine* has been completed but some data are being collected for three other minor Ptinids, *Tipnus unicolor*, *Ptinus pusillus* and *P. hirtellus*. Some success has been achieved with the culturing of *P. villiger* by subjecting the adults to low temperatures in a refrigerator, but the difficulty of culture suggests that this insect can never be as serious a pest in Britain as it is in Canada. (*R. W. Howe, H. D. Burges, Miss J. E. Currie*).

LIFE HISTORY AND PHYSICAL LIMITS OF *Dermestes frischii*

Laboratory work on this species, one of the Hide beetles, has shown that the larvae die at 40°C although eggs can hatch. The optimum temperature for rapid development on fishmeal at 70 per cent relative humidity is 33° C (Fig. 2). Growth was obtained from 37.5°C down to 20°C, the lowest temperature used. This species is very susceptible to low humidity, which greatly prolongs the period of larval feeding and increases the death rate. All larvae die at 40 per cent relative humidity. (*R. W. Howe, Miss J. E. Currie*).

DEVELOPMENT OF *Oryzaephilus*

The difference between the food preferences of the two species of *Oryzaephilus* has been confirmed by laboratory experiments. The Saw-toothed Grain beetle, *O. surinamensis*, completes development more quickly than does the Merchant Grain beetle, *O. mercator*, on wheatfeed, a cereal product; but *O. mercator* is the faster on coconut meal, an oilseed product. Nevertheless, *O. mercator* develops more quickly on wheatfeed than on coconut meal. Both species can withstand low humidities on wheatfeed but are more susceptible when fed on coconut meal; on this food *O. surinamensis* fails at 50 per cent relative humidity. *O. surinamensis* lays eggs at about twice the rate of *O. mercator* for most of the prolonged laying period (about four times as long as developmental period), but *O. mercator* lays eggs for a rather longer period. Complete development for both species is possible at 37.5°C but not at 40°C. Eggs do not hatch at 15°C but do so at 17.5°C; complete development has not yet been recorded below 20°C. (*R. W. Howe*).

LIFE HISTORY OF THE RUST-RED FLOUR BEETLE

Although *Tribolium castaneum* has been used in many experiments in laboratories all over the world, its life history has not hitherto been studied over a wide range of temperatures and humidities. Experiments covering temperatures from 20 to 40°C and relative humidities from 10 to 90 per cent with wheatfeed as food are now completed. (*R. W. Howe, Miss S. M. Nightingale*).

BIOLOGY OF TYROGLYPHOID MITES

(1) *Survival and increase*

Work on the examination and analysis of the data on the life history and physical ecology of the Flour mite, *Tyroglyphus farinae*, has been continued and is now almost finished.

A number of biological problems, chiefly of interest in relation to the technique adopted in the life-history work, but also of some general interest, have been investigated. It was found that virgin *T. farinae* females laid no eggs and lived much longer than fertilised females. Repeated copulation was necessary for the female to produce the maximum number of eggs, and the removal of the male early in an experiment caused a cessation of egg laying after 11–17 days (at 90 per cent relative humidity, 15°C). It was also observed that when this happened the adult life of the female was prolonged. Re-introduction of the male caused a resumption of egg-laying. The effect of keeping an excess of males in the breeding cell with a female in the ratio of 3 : 1 caused a rapid drop in the average total number of eggs laid compared with the number laid by a female paired with a single male, and also caused the early death of

the female. It is possible that simple crowding effects played some part in this result. Both sexes were found to require food in the adult stage; starvation caused early death and prevented egg laying.

The life-history studies started last year on *Tyrolichus casei* and *Tyrophagus castellanii*, two species of Tyroglyphoid mites often associated with *Tyroglyphus farinae* on a wide range of food products, have been continued on a limited scale at 15°C. Some data are now available showing the differences in developmental times between the three species when bred on the same food material—wheat germ—at this temperature. The figures are given below, those for *Tyroglyphus farinae* being taken from earlier work.

Species	Mean developmental time (egg to adult) in days at 15°C.		
	R.H. 90%	R.H. 80%	R.H. 70%
Tyroglyphus farinae	20.2	23.6	32.1
Tyrolichus casei	34.6	39.3	No data
Tyrophagus castellanii ..	28.2	43.8	61.2

At 70 per cent relative humidity the juvenile mortality in *Tyrophagus castellanii* was very heavy, hence the figure for development is based on a small number of individuals. A number of these experiments which are still in progress will give data on egg production, adult life, mortality, etc. (*A. M. Cunnington, Miss M. Jackson*).

(2) *Resistance of flour mites eggs to low humidity*

Experiments to determine the degree of tolerance of the eggs of *Tyroglyphus farinae* to drying have continued. At 5°C, a few eggs survived 30 days at 50 per cent relative humidity, 25 days at 40 per cent or 20 days at 20 per cent relative humidity. None survived 25 days at 30 per cent or 20 per cent relative humidity. At 10°C, a few eggs survived 30 days at 60 per cent relative humidity, but none survived 20 days at a relative humidity of 50 per cent.

As in earlier experiments, the mortality has been rather variable and some of the more detailed results appear anomalous. At 5 and 10°C, there is a rapid effect of drying which kills a proportion of the eggs within the first day, but to bring about any appreciable increase in this mortality, about two weeks exposure is necessary. (*A. M. Cunnington*).

(3) *Relative susceptibility to mite attack of Manitoba and Durum wheats*

As a result of an enquiry from the Infestation Control Division of the Ministry of Agriculture and Fisheries, an investigation has been started to determine whether Durum wheat (*Triticum durum*) is more susceptible to mite attack than Manitoba wheat (*Triticum vulgare*). As a first step the moisture content—relative humidity relationship of the two wheats has been determined at 75

per cent relative humidity and 20°C. No significant difference has been found. (*A. M. Cunnington*).

(4) *The hypopus stage.*

Further experiments to find the particular environmental conditions which will evoke the formation of the hypopus stage in the Flour mite, *Tyroglyphus farinae*, have added little to what was found last year, and have been discontinued until observations supply new clues. Meanwhile, experiments are in progress to find the effects of environmental conditions (primarily temperature and humidity) on hypopus formation in the Furniture mite (*Glycyphagus domesticus*), and in the related *Glycyphagus destructor* which is common on many stored products. (*M. E. Solomon*, *Miss R. Borrett*).

METHODS OF CALCULATING RATE OF INCREASE OF INSECT POPULATIONS

The calculation of the rate of population increase corresponding to given rates of development, reproduction, and mortality is generally somewhat complicated, involving the use of demographic methods adapted for zoological use by P. H. Leslie and by L. C. Birch. To provide short cuts and simplify the procedure, graphs and tables have been prepared and submitted for publication. (*R. W. Howe*).

TAXONOMY OF BRITISH SPECIES OF *Cryptophagus*

Beetles of the family Cryptophagidae feed upon moulds, and are consequently found associated with stored products under damp conditions. Several species were found during the birds' nest survey and the work on residual infestations. Attempts to identify these insects by means of existing keys indicated that the group was badly in need of revision, and this has been undertaken. Large numbers of identifications have been carried out and it is hoped to produce a workable key to the British species in the near future. (*G. E. Woodroffe*, *C. W. Coombs*).

BIRDS' NESTS AS A SOURCE OF PESTS

Work on the birds' nest survey during the year has been confined to examination and interpretation of results, study of the literature, and preparation of a paper for publication. (*G. E. Woodroffe*).

BIOLOGY OF CARPET BEETLES

(1) *Field distribution and origin of infestations*

The survey of the three common carpet beetles which was started last year was again undertaken during the summer months. It has now been extended to include distribution of *Anthrenus verbasci* in infested premises. Much useful information has been obtained, and there is now some evidence to support the following general conclusions :—

A. verbasci occurs out-of-doors on flower-heads in very large numbers only in the south-east of the country.

Greater numbers are found in modern suburban areas than in rural areas and city centres.

Complaints of damage from householders have come largely from the type of areas in which the highest flower-head populations occurred.

A. verbasci is the typical nest-dwelling species. *A. fuscus* is found more commonly under bark, near spiders' webs, and in similar situations.

There is not conclusive evidence concerning the larval habitat of *A. museorum*, but it is probably similar to that of *A. fuscus*. The results of the birds' nest survey indicated that house-sparrows' nests were probably of some importance in causing household infestations. The study of infestations in private houses suggests that such nests are of primary importance. In a high proportion of cases, the larvae causing damage in private houses had wandered from some source, usually a sparrows' nest in the roof space. A usual feature was the infestation of woollen material used for lagging water-pipes in the roof space. Larvae then wandered down the water-pipes into the airing cupboard. Frequently the first damage noticed by the householder occurred here, and often clean (or completely new) articles were damaged.

Infestations arising from adult beetles entering inhabited rooms and ovipositing directly upon woollen materials seem to be rare.

Very occasionally the only source appeared to be nests in an adjoining building. In these cases it seems probable that direct attack by ovipositing adults occurred.

In those cases where the roof-space contained no nest or other source of infestation, small numbers of larvae were found evenly distributed throughout the attic on rafters, beams, etc., where they appeared to subsist on the dust typical of such places, and also on wind-borne seeds, dead insects, etc. On two occasions the nests of leaf-cutting bees appeared to be the original source of the infestations. (*G. E. Woodroffe*, *B. J. Southgate*).

(2) *Behaviour*

The experimental analysis of the behaviour of *Anthrenus verbasci* has been continued from last year. Adult beetles have again infested nest material taken from sparrows' nests, heat-sterilised, and put into boxes which were hung on the walls of the Laboratory below the eaves. The stimulus which leads the beetles to the nest to oviposit is probably an olfactory one. Preliminary experiments on flight have shown that marked beetles can detect and reach Hogweed (*Heracleum spondylium*), Goutweed (*Aegopodium podagraria*), and Spiraea (*Astilbe* sp.) at a range of forty yards in less than twenty minutes. All attempts to attract the beetles by coloured papers and white papers treated with various odours have failed. A suction trap which was running continuously during the adult flight season also failed to catch Carpet beetles.

Young larvae have been shown to be attracted to the smell of fishmeal, crushed insects, woollen sweepings and fresh sparrow droppings.

When given a choice of substrates, the females lay significantly more eggs in fibrous than in granular materials. Woollen sweepings were significantly more attractive as an oviposition substrate than any of seven others tested. Preliminary experiments on the number of eggs laid by adult females showed that there was a great deal of variation and no obvious effect of food. (*Mrs. G. M. Blake*, *Miss R. Borrett*).

(3) *Life history and physical limits.*

Experiments on the duration of the larval period of *Anthrenus verbasci* which were started in 1951 are now nearly complete. Observations were made at 30 and 70 per cent relative humidity at temperatures of 5°, 10°, 15°, 20° and

25°C. Relative humidity had little effect. Larvae failed to develop at 5° or 10°C. At 15°C, only a few had pupated by the 15th month. The optimum temperature for development was 20°C. At 20° and 25°C, about 75 per cent of the larvae in each experiment became adults in 5 to 9 months, while the remainder have not reached the pupal stage after 15 months. Omitting these stragglers, the mean larval period was as follows :—

approx. 6 months at 20°C.
approx. 8 months at 25°C.

Further experiments have been set up at 17.5°C and 22.5°C.

In a study of the effects of alternating temperatures on development, three incubators in a room controlled at 18°C were heated for 12 hours each day. The ranges were 18–23°, 18–28° and 18–33°C. At 18–23°C, which is well within the developmental range, the larval period was about 6 months, which is the value that would be expected at the mean temperature, 20.5°C. At 18–28°C, where the upper limit was well above the optimum, the larval period was just over 8 months, and thus longer than one would expect at the mean temperature, 23°C. At 18–33°C, where the upper limit was above the developmental maximum, the larval period was again lengthened. The mean temperature was 25.5°C, but the larval period was nearly 10 months.

Experiments are in progress to determine the lethal heat treatment required to kill this species. Three hours at 45°, 1 hour at 46°, 20 minutes at 48°, or 10 minutes at 50°C killed the fully grown larvae in closed glass vessels immersed in a water bath. The relative humidity was controlled at about 70 per cent. No other stages have yet been tested except the young larvae, which are less resistant than the old. (*Mrs. G. M. Blake*, *Miss R. Borrett*).

TECHNICAL DEVELOPMENTS

The technique of embedding insects in transparent plastic blocks has been used in the production of a number of specimens for demonstration purposes in the Laboratory and elsewhere. The material used is methyl methacrylate (Perspex). The process is lengthy and difficult, but some excellent mounts have been made. It is hoped to produce a collection of adults and larvae of storage pests in a more life-like and durable form than is possible by other methods. (*B. J. Southgate*).

Practical difficulties have delayed the production of cobalt thiocyanate paper by a scientific supply firm, but it is hoped that this material for the measurement of humidity will soon be generally available. (*M. E. Solomon*).

GRAIN STORAGE AND MYCOLOGY

There have been fewer changes of staff in 1952 than in previous years. Mr. Disney returned from military service in January and has resumed full-time duties in the Section.

Mr. Oxley was absent for the last two months of the year on a visit to Malaya, at the request of the Colonial Office and the Malayan Government, to study and advise on problems of rice storage in the Colony.

The appointment of a Colonial Liaison Officer at the Laboratory has brought increasing work to the Section, particularly of an advisory nature.

For example, air-tight underground storage bins, made to the design recom-

mended by the Section, have been erected for trial in Tanganyika and Nyasaland. (*T. A. Oxley*).

The need for a quick and simple method of determining moisture content in bagged produce, particularly in the Colonies, has led to experiments on methods based on measuring the electrical resistance of cereals. An apparatus which appears satisfactory in practice has been developed and is now being calibrated. (*T. A. Oxley, D. Budd*).

The Laboratory is represented by Mr. T. A. Oxley on a Committee set up in January 1952 by the Ministry of Agriculture and Fisheries to study the question of the use of portable grain silos on farms in Great Britain. Advice has been given on the structure of the various types of silo, and on the observations that should be made on the prefabricated silos of steel, aluminium, plywood, and concrete that are being erected for experimental purposes at the National Institute of Agricultural Engineering.

The Section is collaborating with other research institutions in the basic scientific investigations necessary for this work, and in studying, in particular, the theoretical principles and conditions of dew formation in contact with grain and in the free space above grain in a covered silo, the tolerance of grain to repeated intermittent dewing, and the determination of the water vapour isotherm at temperatures below normal, down to freezing point. The work is at present at the stage of developing methods and acquiring the necessary apparatus. (*T. A. Oxley, R. W. Disney*).

RELATION BETWEEN SPECIFIC HEAT AND MOISTURE CONTENT OF GRAIN

A method of determining the specific heat of grain has been developed, with a view to studying the variation with moisture content. It is hoped that, apart from the obviously useful data on specific heat that will be obtained, some light will be thrown on the type of water-binding found in grain.

The apparatus used is an ice calorimeter which has been calibrated electrically. The grain to be tested is conditioned to a known moisture content, and a series of specific heat determinations is carried out on the sample. It has been found that a series of twelve determinations at each moisture content is necessary in order to reduce the standard error to an acceptable value.

The work has so far been confined to a study of wheat, but it is hoped to extend the investigation to other cereals in the near future. The results for wheat are not at present sufficiently complete to attempt analysis, but they seem to indicate a near linear relationship between specific heat and moisture content. (*R. W. Disney*).

RESPIRATION OF GRAIN IN RELATION TO MICRO-ORGANISMS

The results reported last year, that increase in respiration at high moisture content of grain is due largely to external micro-organisms, have been confirmed by a further series of experiments. The method is now being extended to enable simultaneous measurements to be made at a range of moisture contents. (*Miss M. B. Hyde*).

EFFECT OF FUMIGATION ON GRAIN MICRO-ORGANISMS

Following the preliminary experiments described in last year's annual report, a small-scale screening technique was devised to test known insecticidal fumigants for fungicidal properties.

In this method dry fungus spores on glass slides were exposed to a series of concentrations of the test gas at atmospheric pressure in one-litre flasks. The slides were then aired and incubated in a humid chamber. An estimate of percentage spore germination was made after 48 hours.

Most of the fumigants tests were fungicidal only at very high concentrations. Ethylene oxide, the most promising substance tested, gave 100 per cent spore kill at a concentration of 20 mg/l. for 18 hours. (*G. Ayerst*).

DAMP GRAIN HEATING

During the year there have been several instances, reported through the Infestation Control Division of the Ministry of Agriculture and Fisheries, of heating in damp grain in the absence of insect attack. This "damp grain heating", due primarily to the increased metabolism of micro-organisms when grain has a high moisture content, is being studied by relating observations made in the field to the results of laboratory investigations.

Instances of this type of heating in wheat in East Anglia and in maize in Wales have been studied in the field, and samples of maize, wheat, barley, etc., suspected of being capable of such heating by giving high CO_2 figures in the absence of insects, have been received at the Laboratory for examination.

In addition to the identification of the micro-organisms present, an approximate numerical assessment of their abundance is required. A standard mould counting technique to apply to such samples is being developed. (*Miss M. B. Hyde, G. Ayerst, D. Budd*).

MYCOLOGICAL FOOD STORAGE PROBLEMS

In the report for 1951 an investigation of a white deposit which develops on Brazil nuts during shipment was reported. This work has been continued in the laboratory and by examination of cargoes of nuts on board the ships.

The organisms isolated from the deposit have been identified as belonging to the Actinomycete genus *Streptomyces*. Attempts have been made to induce the white deposit to develop on normal nuts by inoculating them with these organisms. Although this has so far been unsuccessful, it has been found possible to infect normal nuts directly from nuts showing the deposit. Experiments to determine the optimum physical conditions for the development of the deposit are continuing.

Inspections of several cargoes of nuts before and during unloading have been carried out. On the latest occasion temperature recording and gas sampling apparatus was sent out to Brazil from the Laboratory to be installed in the cargo and used during the voyage to England. Unfortunately this particular cargo was abnormal in some respects and the information obtained was less useful than might have been expected.

It is intended to continue the work on this problem during next season. (*T. A. Oxley, G. Ayerst*).

HERMETIC STORAGE OF GRAIN

For some years reports have been received in this country of the use, in France, of storage under strictly air-tight conditions to preserve native grain directly after harvest. It has been generally thought in Britain that such a

procedure would be safe only for dry grain, and that it would be unlikely to be of value for home-grown grain in Britain.

During September 1951, however, Dr. E. A. Parkin of this Laboratory took the opportunity provided by a visit to Paris to examine an air-tight storage installation where grain of apparently high moisture content (probably about 20 per cent) was being successfully stored. From Dr. Parkin's report it seemed evident that the process might be of very considerable value in British practice. It was realized that, even if slight injury to grain quality resulted, this might not be important to the British miller whose grist seldom contains as much as 30 per cent of native wheat, and frequently less.

If the process can be used satisfactorily for damp grain, not only would there be the saving of the cost of drying, which might more than offset, over a period, the cost of the air-tight storage bins, but there would also be less strain on the capacity of drying plant in the crucial period immediately after harvest, particularly by combine harvesters. In addition there would be savings in fuel and labour, and also the saving in saleable weight which is lost (by evaporation of water) when grain is dried.

In order to obtain a first-hand opinion of French practice, Mr. T. A. Oxley, Miss M. B. Hyde, and a member of the Agricultural Land Service of the Ministry of Agriculture and Fisheries visited France in May 1952, to examine installations where grain was stored under hermetic conditions, to discuss the constructional details with silo engineers, etc., and to attempt to form an unbiassed opinion of the value of such storage. The results of the visit indicated that, in French experience, grain of high moisture content is better preserved by hermetic storage than by storage under ordinary conditions. These findings were based purely on the results of storage in practice and, apart from some comprehensive experiments by A. Blanc in 1938 using wheat with a maximum moisture content of 16.2 per cent, they had no sound scientific basis.

In view of the obvious advantages to British agricultural economy if hermetic storage of damp grain were satisfactory, the Laboratoray has begun investigations to study the scientific basis of such storage on a laboratory scale. The work will be extended to a semi-commercial scale during 1953. For this purpose three air-tight 10-ton bins of welded steel have been erected at the Laboratory.

Measurements will be made of the concentration of inter-granular carbon dioxide and oxygen, of the humidity and temperature, in various positions in the bins, at intervals during the storage period. The effect of storage on the milling and baking quality of the grain is being studied with the co-operation of the Research Association of British Flour Millers. (*T. A. Oxley, Miss M. B. Hyde*).

INSECTICIDES

The good progress made by the Section has been in part due to the fact that for the first year in its history there has been no change of staff and therefore no loss of time in training new members. For the second year in succession it has not been possible to do a full-scale test of the surface treatment of bulk grain with a powder containing pyrethrins and piperonyl butoxide for controlling moth infestation, because the Infestation Control Division, Ministry of Agriculture and Fisheries, were unable to locate a suitably infested stowage.

Pressure of other work prevented another experimental treatment of a farm granary to determine the effect of an insecticidal treatment by sample counting of insects.

STATISTICAL ASPECTS OF INSECTICIDAL ACTION

In collaboration with Mr. R. L. Plackett of the Department of Applied Mathematics, University of Liverpool, the quantal response of insects to a mixture of poisons synergising or antagonizing one another has been formulated in a general manner. A lecture on the results of this and previous work has been given to the Royal Statistical Society and will be published shortly. (*P. S. Hewlett*).

ADJUVANTS IN HEAVY-OIL SPRAYS

Laboratory experiments have been carried out to determine the effects of a number of adjuvants on the toxicity to Flour beetles, *Tribolium castaneum*, of pyrethrins, gamma-BHC, and DDT in Shell oil P31. The adjuvants were substances which were known to synergize the action of pyrethrins on house-flies. Intermediate solvents were added where necessary. The results are indicated in Table I.

TABLE I.

The effect of adjuvants on the toxicity of Pyrethrins BHC, and DDT in P31.

	Pyrethrins		BHC		DDT	
	Direct spray	Film	Direct spray	Film	Direct spray	Film
Piperonyl butoxide	+	+	+	(+)	O	—
Piperonyl cyclonene	+	+	+	O	O	O
Isosafrole and *n*-propyl maleate condensation product.. ..	+	+	(+)	O	—	—
n-octyl sulphoxide of isosafrole ..	+	+	+	(+)	+	O
Piperonyl-2-acetyl-4-amyl cyclohexanedione (3.5)	+		+			
n-octyl bicycloheptene dicarboximide	O	O	O	O	(+)	(+)
Eugenol	O					
Methyl eugenol	O					
N-isobutylundecylenamide.. ..	O	O				

+ Marked synergism (+) slight synergism O no effect (—) slight antagonism — marked antagonism.

None of the adjuvants alone was appreciably toxic to *T. castaneum* under the conditions of test. The first five adjuvants listed, which are methylenedioxyphenyl compounds, all synergized pyrethrins under both conditions of test and BHC as direct sprays. The synergism of BHC in direct sprays, though very definite, was not nearly so great as that of the pyrethrins. Other workers have shown that the presence of a methylenedioxyphenyl group greatly enhances the likelihood of a compound being synergistic with pyrethrins. The results now obtained with *T. castaneum* strengthen this view and show that a similar condition probably holds good in the synergism of gamma-BHC. Where a difference occurred between the results for the two methods, less synergism, or more antagonism, was apparent in the film tests than in the direct spray tests.

There is no reason to think that any of the adjuvants so far tested is generally more suitable than piperonyl butoxide for inclusion in the P31 sprays used against stored product insects. (*P. S. Hewlett*, *Miss C. Belcher*).

IMPREGNATION OF SACKING

The protection afforded by jute sacking impregnated with pyrethrins and piperonyl butoxide is being further investigated in collaboration with the British Jute Trades Research Association. Tests are in progress to determine the durability of the impregnation treatment, under both laboratory and semi-field conditions. (*E. A. Parkin*, *P. S. Hewlett*, *Miss K. D. Lambe*, *Miss M. A. Cant*).

MICRO-DROP APPLICATOR

This instrument has been used on an increasing scale and the technique of handling the insects that was devised previously has proved rapid and satisfactory. The applicator is illustrated in Plate I and a description of it is being written for publication. (*P. S. Hewlett*, *Miss C. Belcher*).

SPEED OF RESPONSE OF *Trogoderma* LARVAE TO INSECTICIDE

Previous experiments had indicated that the larvae of Khapra beetles, *Trogoderma granarium*, were very resistant to insecticide; but it was not clear whether low mortalities among treated batches were due to true resistance (i.e. toleraation of high doses), or to slow death after the application of lethal doses, or to both factors. In order to investigate the point, batches of larvae were sprayed with pyrethrins in odourless kerosene, and the numbers dying observed frequently over the succeeding 45 days, during which the larvae were kept at 25°C and 70 per cent R.H. Larvae died from pyrethrum poisoning at intervals over a period of at least 27 days after spraying and detailed analysis of the results led to the conclusion that the larvae are both highly resistant to pyrethrins and very slow to die from lethal doses.

During the early part of the observation period the dose-mortality relation was inverted, i.e. the lower the dose of pyrethrins, the higher the mortality : the inversion was shown to be significant. Theoretical considerations show that a transient inversion of this kind need not be regarded as anomalous. (*P. S. Hewlett*, *Miss K. D. Lambe*.)

EFFECT OF SUB-LETHAL DOSES OF PYRETHRINS ON FECUNDITY

To test the effects of sub-lethal doses on fecundity, adult Grain weevils, *Calandra granaria*, and Flour beetles, *Tribolium castaneum*, were directly sprayed with a dose of pyrethrins in Shell oil P31 sufficient to kill about 80 per cent of the insects. The surviving 20 per cent were put on foodstuffs to breed, and their fecundity was found not to have been appreciably impaired. (*Miss K. D. Lambe*).

BIO-ASSAY OF PYRETHRINS BY A GRADED RESPONSE

Several years ago it was observed at the Laboratory that Flour beetles, *Tribolium castaneum*, lost weight rapidly on being treated with pyrethrins, the weight lost in a given time being related to the dosage of the insecticide. This suggested the possibility of a bio-assay method for pyrethrins in which the (graded) response of the insects could be determined simply and rapidly by weighing each batch before and after exposure, instead of determining the (quantal) response in terms of death, etc., which involves the tedious examination and classification of each insect in each batch employed.

Investigation of a number of factors influencing the weight loss of the beetles on films has contributed to the evolution of the bio-assay method. The procedure for bio-assay is, briefly, as follows:—Whatman No. 544 filter papers are sprayed with pyrethrins in P31 at a fixed level of deposit. Papers of one series are treated respectively with dilutions of a standard concentrate of known pyrethrin content, and those of another series with dilutions of the preparation of unknown pyrethrin content. Beetles, in batches of 100 each weighed to the nearest 0.1 mg, are exposed on the papers for 3 h at 25°C and 70 per cent R.H., after which they are removed and weighed again. Control batches are similarly exposed on untreated papers. Under the conditions of exposure, the maximum weight loss, adjusted for that in the controls, is about 7 per cent of the initial weight, however high the pyrethrin concentration. The weight of the insecticidal solution adhering to the bodies of the beetles is negligible. By suitable statistical analysis the losses in weight of the batches of beetles can be used to estimate the potency of the " test " preparation relative to the standard, whence the pyrethrin content of the former can also be estimated. A slight disadvantage of the method is that the analysis of the results is a little more complicated than in quantal-response assays.

This method of bio-assay is applicable to allethrin, and there are indications that it can be adapted for use with BHC and other insecticides. Experiments have also indicated that the method will work if the pyrethrins are in lighter oils. Certain species of stored product beetles other than *T. castaneum*, in particular *T. confusum*, also lose weight rapidly enough for bio-assay purposes, but some species do not.

The physiological aspects of the loss in weight are now being investigated. (*P. S. Hewlett, Miss M. A. Cant*).

RESIDUAL TOXICITY OF INSECTICIDAL FILMS ON BRICKS

Additional preparations to those reported on in 1949 and available for application to surfaces in warehouses, etc., have been tested to compare their persistence : (i) a wettable powder containing 50 per cent DDT, (ii) an oil-bound concentrate containing 52 per cent DDT, and (iii) an emulsifiable concentrate containing 18 per cent DDT with a synergist. They were applied by

pipette to Fletton bricks to give a deposit of about 90 mg DDT per sq. ft. ; the coatings were allowed to dry, and the bricks were then stored at 25° and and 70 per cent R.H. Flour beetles, *Tribolium castaneum*, were confined on the coatings at intervals.

The coatings all remained highly toxic to the beetles for over eight months, though their toxicities decreased somewhat during this period. There were no notable differences in toxicity between the residues left by the various preparations. (*Miss M. A. Cant*).

EVALUATION OF SYNTHETIC MATERIALS AS INSECTICIDES

(1) *Aldrin and dieldrin.* The toxicity to Flour beetles, *T. castaneum*, of aldrin and dieldrin applied in Shell oil P31 as direct sprays, and as films on filter paper, has been determined. The two materials were closely similar in toxicity and both highly toxic—rather more toxic than gamma-BHC. Neither was synergized in direct sprays by piperonyl butoxide. The toxicity of mixtures of aldrin and dieldrin in direct sprays indicated that the physiological action of the two materials is similar, as might be expected from their chemical similarity. (*P. S. Hewlett, Miss C. Belcher*).

(2) *Dimetan and pyrolan.* Tests have indicated that these two urethane derivatives are of low toxicity to Grain weevils, *Calandra granaria*, and Flour beetles, *T. castaneum.* They were also found to be somewhat less toxic to normal houseflies than DDT, but have been reported to be toxic to DDT-resistant flies. (*Miss K. D. Lambe, Miss M. J. Kane*).

(3) *Valone* (2-*isovaleryl*-1, 3-*indandione*). In P31, valone is highly toxic to *C. granaria* and *T. castaneum*, though not so toxic as pyrethrins—of the order of one-third as toxic as pyrethrins to *T. castaneum.* Valone proved, however, to have a property of considerable physiological interest, namely a fast lethal action : it kills *T. castaneum* about three times as rapidly as do the pyrethrins. The action of Valone on *T. castaneum* was not synergized by a number of compounds which synergize the action of pyrethrins on houseflies. (*P. S. Hewlett, Miss C. Belcher*).

(4) *Some biological tests on houseflies* have been performed on behalf of Dr. L. Crombie, Imperial College of Science and Technology, London, to determine how two synthetic isomers of N-isobutyl-deca-2, 4-dienyl amide compared in toxicity with natural pellitorine. Tests in the small fly-spray chamber showed that the one isomer was about 0.4 and the other isomer about 0.03 times as toxic as the natural material. (*E. A. Parkin, A. A. Green, Miss M. J. Kane*).

CONTROL OF BEAN WEEVILS

The help of the Laboratory has been sought through the Colonial Liaison Officer to improve methods of protecting beans in East Africa from severe infestation by Bean weevils (family Bruchidae). These beans are intended partly for export and partly for local consumption. Since it is clearly desirable to use, if possible, insecticidal materials which are easily available locally, a Kenya diatomite powder with and without the addition of BHC is being investigated first. Samples of this powder and of haricot and mixed beans have been received for investigation.

It was proposed to use two species of Bean weevils, *Acanthoscelides obtectus* and *Callosobruchus chinensis*, in the tests : the beans sent were already infested with the former. Considerable difficulties, however, have been met in breeding

Micro-drop applicator for bio-assay of insecticides

PLATE I

(*a*) Release of 'marked' flies

(*b*) A typical trap site, showing small type of trap

Migration of blowflies

PLATE II

(*a*) A typical trap site, showing large type of trap

(*b*) Testing the 'catch' for radioactive flies

Migration of blowflies

PLATE III

(A) *Ant control in a hospital. Spraying insecticide in heating duct*

(B) *Preparing gas sampling tubes prior to the fumigation of a large bulk of grain*

PLATE IV

the two species on the scale necessary for the insecticidal testing. *A. obtectus* has now been found to breed well on haricot beans at 30°C, but not so well at 25°C : it will not breed satisfactorily on peas at either temperature. The *A. obtectus* from the African beans were much more prolific than the existing Laboratory strain. *C. chinensis* breeds well on peas at both 25°C and 30°C but this species does not breed satisfactorily on beans at either temperature.

Now that the breeding difficulties have been overcome, the insecticide tests are under way. (*Miss K. D. Lambe*).

RESISTANCE OF SOME GRAIN INSECTS TO BHC DUST

A dust containing 0.5 per cent of gamma-BHC has been mixed with wheat and four species of insects have been kept on appropriate ranges of concentrations, as determined from preliminary rough tests, from 0.625 to 20 parts per million. The two Granary weevils, *C. granaria* and *C. oryzae*, were controlled in these tests by 1 p.p.m. or less of gamma-BHC in the grain. The Flour Beetle, *T. castaneum* was not killed by 5 p.p.m. but no offspring were produced : this may have been due to death of the eggs from the effects of the BHC vapour which accumulated in the glass jars. In contrast, 20 p.p.m. of the gamma-BHC were needed under similar conditions of exposure to prevent breeding by the Saw-toothed Grain beetle, *Oryzaephilus surinamensis*, and the adult beetles seemed scarcely affected during the exposure period of 21 days.

These results indicate that big differences in resistance to gamma-BHC can occur among stored product insects and support field observations that *Oryzaephilus* has survived treatment with this insecticide when other insects have been killed. It is difficult to relate the laboratory results with any exactness to practical conditions, however, because of the variability of the vapour concentration (an important part of the toxic effect of this insecticide) in practice. (*E. A. Parkin, G. T. Bills*).

PROTECTION OF GRAIN BY BENTONITE

A sample of an Italian bentonite powder was obtained which was stated to be effective in protecting stored grain against insect infestation. The finely ground mineral was to be admixed with grain at the rate of 0.2 per cent by weight, provided that the moisture content of the grain did not exceed 12.5 per cent. Preliminary tests with dosages from 0.1 to 0.4 per cent in grain of 12 and 14 per cent moisture content as a protectant against the Grain Weevil, *Calandra granaria*, did not confirm the results reported by Italian workers. (*E. A. Parkin, G. T. Bills*).

DDT-CONTAMINATION OF WHEAT IN STORE

The risk of transfer of DDT from impregnated sacking to grain stored in it was investigated several years ago. Additional information has now been obtained of the levels of contamination which may be expected from storage of wheat in bulk or in bags against treated surfaces or from exposure to deposits from DDT-smoke generators. It was reassuring to find that, although DDT was always picked up to some extent from the treated surface, the normal recommendations in this country concerning minimum depths of grain to be treated are well founded. (*E. A. Parkin, B. P. Moore, A. A. Green*).

BIO-ASSAY OF TANGANYIKA PYRETHRUM

The pyrethrum growers in Southern Tanganyika sought the assistance of the Laboratory to decide whether seeds of a newly developed strain of pyrethrum plants should be issued for commercial cultivation. The decision could not be made on the basis of chemical assay alone because the toxicity to insects of some high-yielding strains of pyrethrum has been suspected to be less than that expected from the results of chemical assay. Since the Insecticide Section was intending at some time to compare the results from different methods of bio-assay for pyrethrins, this seemed an excellent opportunity to do the experiment and help the Tanganyika growers at the same time.

Samples of three strains of flowers (U, K, and CB) were submitted to the Pest Infestation Laboratory, where they were ground to pass a 30-mesh screen for extraction and a 100-mesh screen for use as insecticidal dusts. Extracts of each 30-mesh powder were prepared so as to yield nominal 7.00 per cent w/v concentrates of pyrethrins in Shell oil P31. The chemical analyses to determine the pyrethrins I and II contents of the flowers were made on the concentrates and biological rests were made as follows :—

(i) knock-down and kill of *Calandra granaria* in grain treated with pyrethrum powder;

(ii) knock-down of *Calandra granaria* by deposits on filter paper of solutions of the pyrethrins in Shell oil P31;

(iii) kill of *Tribolium castaneum* exposed to direct sprays of solutions of the pyrethrins in Shell oil P31;

(iv) weight loss from *Tribolium castaneum* (as described earlier in this report);

(v) kill of houseflies (*Musca domestica*) by space sprays of solutions of the pyrethrins in refined kerosene.

The results of the Laboratory's tests are summarized in the accompanying table.

Test	Relative potency		
	U/CB	K/CB	U/K
Chem. assay (based on pyrn. I)	1.20	1.12	1.07
Chem. assay (based on pyrn. I + II) ..	1.26	1.01	1.25
K-D and kill of *Calandra* (dust)	1	1	1
K-D of *Calandra* (extract)	1.58*	1.20*	1.32*
Kill of *Tribolium* (extract)	1.14*	1.35*	0.85*
Weight loss *Tribolium* (extract)	1.42*	1.30*	1.09
Kill of *Musca* (extract)	1.18	1.11	1.06

* Value significantly different from 1.00.

These assays show that different relative potencies are to be expected in comparing the same group of pyrethrum insecticides by different bio-assay techniques. The U and K strains were always more toxic than the CB, which was the standard for comparison, but in three biological tests U was superior to K, and in two K was superior to U. The potencies of K and CB were equal when compared by chemical assay on the basis of total pyrethrins, but the biological results showed that K was definitely more toxic than CB, a situation also shown by comparing the strains on the basis of their pyrethrin I contents. (*E. A. Parkin, P. S. Hewlett, B. P. Moore, A. A. Green, G. T. Bills, Miss M. A. Cant, Miss M. J. Kane, Miss C. Belcher*).

CHEMICAL INVESTIGATIONS ON CONTACT INSECTICIDES

An extensive study of the chemistry of the pyrethrins and related compounds has been initiated, with particular emphasis on properties of possible analytical importance. Several new and interesting reactions have been discovered and attempts are being made to develop one of them as a basis for pyrethrum assay.

In addition a considerable amount of collaborative work with other Laboratories has been undertaken in order to find improved methods for the determination of DDT, BHC, and pyrethrins. (*B. P. Moore*).

MOTHPROOFING TESTS

A meeting of the Mothproofing Committee of the International Wool Trade Organization in Paris in January was attended by Dr. E. A. Parkin to discuss the results of the collaborative tests undertaken by seven Laboratories on an international basis, as described in the previous Annual Report. The results however failed to show any clear advantage of the British over the Swiss method, or vice versa, and it was agreed to submit them to statistical analysis. Both methods have now been shown to be about equally variable and the level of variability is, from a statistical viewpoint, too high. The four British Laboratories are therefore now trying a method of assessing mothproofing efficiency which involves a somewhat different approach to the problem and will, it is hoped, reduce the variability inherent in the existing methods. The results from the participating Laboratories are now being statistically analysed.

In 1951, it was reported that a difference of 1°C in the breeding temperature of the Common Clothes moth, *Tineola bisselliella*, had a most marked effect on the rate of increase in weight of the larvae. This year, tests have shown that a similar difference in temperature applied only during the 14-day period of exposure did not significantly affect the amount of damage done to a fabric sample.

Some tests have also been made on materials, such as carpet and yarn, which have not so far been investigated at the Pest Infestation Laboratory, in order to get practice in handling them in tests of mothproofing efficiency.

Finally, in case larvae of the Carpet Beetle, *Anthrenus vorax*, should prove an acceptable test insect with which to determine proofing efficiency, an experiment has been made to determine how many larvae can be exposed without overcrowding upon a standard sample of fabric under the standard conditions of test. A sample 1·6 in. in diameter will take up to 40 larvae, but 20 are sufficient for the purposes of the test. (*E. A. Parkin, Mrs. P. J. Maycock, Miss D. G. Blackman*).

CONTROL OF CLOTHES MOTHS

(1) Nearly fully grown larvae of *Tineola bisselliela* have been exposed to film on filter paper of DDT, pyrethrum, and gamma-BHC solutions in kerosene a various combinations of concentrations and deposits. Although DDT wa highly toxic to the larvae, it was very slow in action. At similar concentration and deposits 100 per cent mortality of the larvae was not quite attained i 20 days exposure to DDT, but was reached in 7 days or less exposure to gamma BHC or pyrethrum. Larvae sprayed directly with 1·0 per cent DDT in kerosen were killed in 3 days; those sprayed with the solvent alone died in 14-15 days

Samples of wool serge sprayed with household-type sprays of DDT o gamma-BHC in kerosene were allowed to dry for a week and then exposed t moth larvae. A deposit (using a 1·0 per cent solution) of 0·12 per cent by weigh of DDT on the cloth killed all the larvae within 14 days; this amount of DDT when applied to the material by impregnation, would be sufficient to proof th cloth, if tested by the usual technique. Lower concentrations of DDT an correspondingly lower deposits, killed the larvae more slowly and thus allowe them to do a certain amount of damage. With 0·2 per cent by weight of gamma-BHC on the cloth, applied as a 1·5 per cent solution, 100 per cent kill of th larvae was not attained until the 17th day of exposure. This slowness in effec may have been due in part to some loss of the insecticide by volatilization durin the period allowed for the samples to dry. (*Mrs. P. J. Maycock*, *Miss D. G Blackman*).

(2) Inspections have been made of two large premises in which great quantitie of bedding, etc., are stored for long periods and are therefore subject to damag by Clothes moths. In one of the stores, some thousands of mattresses ha become infested or had to be regarded as suspect: fumigation of the mattresse was considered to be the only suitable remedy. Accumulations of fluff (with a high content of wool) underneath pallets on which blankets, etc., were piled and underneath covers to channels in the floor carrying the pipes of the heatin system, were found to be acting as a continuing source of infestation. Genera control measures recommended included thorough cleaning, improved stacking application of residual sprays, and insecticidal smoke treatments. (*E. A. Parkin A. A. Green*).

(3) A heavy infestation by the relatively rare moth, *Monopis crocicapitella*, i the felt lagging to hot-water pipes in narrow concrete ducts under floors in a block of flats was investigated by the Biology Section and referred to th Insecticide Section for experimental treatment. Because the felt was inaccessibl for application of sprays or dusts, DDT-smoke generators were ignited unde the inspection covers. As a result of the treatment moths no longer emerg into the rooms, in contrast to the large numbers seen previously. (*A. A. Green Miss M. J. Kane*).

CONTROL OF CARPET BEETLES

In view of the apparently growing importance, especially in south-easter England, of Carpet beetles (known in their larval stage as Woolly Bears), a programme of laboratory tests has been drawn up to increase our knowledg of the efficacy of various forms of insecticidal treatment. Cultures of thre species, *Anthrenus vorax*, *A. verbasci*, and *Attagenus piceus*, have been establishe to provide insects for the tests. *A. verbasci* is the species most troublesome i this country but its rate of multiplication in culture has so far proved to b

very slow. Preliminary experiments are therefore being made to find whether the quickly breeding *A. vorax* can be used as the primary test insect.

Exposure of half-grown larvae of *A. vorax* and *A. verbasci* to 5 per cent and 10 per cent DDT dusts at 25°C resulted in all *A. vorax* larvae dying within 20 days, whereas not all *A. verbasci* larvae were dead after 44 days. DDT is evidently slow in killing these insects and *A. verbasci* is more resistant than *A. vorax*.

Fully grown larvae of *A. vorax* kept at 25°C in an atmosphere saturated with the vapour of paradichlorbenzene all died within 6 days; the corresponding period for naphthalene vapour was 10 days. (*Mrs. P. J. Maycock*, *Miss D. G. Blackman*).

A considerable number of enquiries, mostly from private householders, have been dealt with this year and to ease the strain of correspondence an account of the life-history, behaviour, and control of Carpet beetles and Woolly Bears has been duplicated for issue. (*E. A. Parkin*).

CONTROL OF BLOWFLIES IN SLAUGHTER-HOUSES

No new experimental work has been carried out but routine observations at the large London slaughter-house showed that continued control measures kept the blowfly population at a relatively low level. There was a general impression that there were fewer immigrating flies than at corresponding times during 1949-50: this reduction in numbers may have been due to the control of flies by our experiments at the nearby refuse-sorting depot. (*A. A. Green*, *A. M. Simmonds*).

CONTROL OF BLOWFLIES IN REFUSE

An analysis has been made of the results of the 1951 experiments at the railway sidings where refuse is collected and sorted in North London. It was estimated from soil samples that, at one time during the height of the season, there were some 25,000,000 blowfly larvae in 15,000 sq. ft. of ground covered by tracks. The aim of the experiments was to prevent such larvae from developing into adult flies which could fly away and infest the surrounding districts. Trapping on untreated plots showed that the normal emergence of adult flies from the area would have been more than 108,000 per day.

By treating the ground with various formulations of DDT and BHC it was found that some control was obtained at larval, pupal and emerging adult stages. When compared on an equal cost basis, dusts were more effective than emulsions and DDT was better than BHC. The most effective treatment was a twice-weekly application of 5 per cent DDT dust which gave an overall control of more than 99 per cent. Recommendations, based on the results of the experiments, were adopted in their entirety by the Borough Council concerned and, for a total cost of about £100, emergence of flies from the area was virtually prevented during 1952.

An examination was made of two very large tips where refuse from London is deposited after transport by rail to a rural area. It was found that larvae were falling from the trucks at the beginning and end of the journey and that the refuse was still heavily infested on arrival at the rural tip. It is reasonable to assume that larvae were distributed along the track for the entire journey from London.

A survey of eight refuse disposal centres in semi-rural areas showed all to be infested with blowfly larvae to about the same extent as London refuse. Two tips, both belonging to the same local authority, were very heavily infested with adult houseflies although few larvae were found. At both places DDT dust was efficiently and liberally applied at least once each day by the authorities. Some of the flies were collected and, in tests at the Laboratory, found to be more resistant than normal to DDT. This is our first experience of heavy infestations of DDT-resistant flies. (*A. A. Green*, *A. M. Simmonds*, *Miss M. J. Kane*, *P. S. Tyler*).

MIGRATION OF ADULT BLOWFLIES

Previous work has shown that vast numbers of blowflies can breed in towns at refuse-disposal centres and slaughter-houses, but no information was available on their rate or range of dispersal. Other workers, in Australia and U.S.A. have shown that blowflies travel up to ten miles in open country but it might be argued that in towns and cities, where there is little need for the adult flies to migrate in search of food or breeding sites, they would remain localized.

Blowflies, which had previously been fed at the Laboratory on a radioactive-phosphorus salt, were released at the refuse-sorting depot at Islington and traps were placed over a radius of two miles (Plates 2 and 3). A preliminary examination of the data shows that the blowflies dispersed at the rate of at least one mile per day and contributed to infestations at shops, canteens, factories, hospitals, etc. A more detailed analysis of the results will be made later when reports of wind and weather conditions will also be studied.

Some collaborative work has been carried out with the Central Public Health Laboratories where samples of trapped flies have been examined for pathogenic organisms. The heat-resistant bacterium, *Clostridium welchii*, was found on all batches of blowflies examined showing that the insects can be at least mechanical carriers of this organism, which is able to cause food poisoning. (*A. A. Green*, *A. M. Simmonds*, *Miss M. J. Kane*, *P. S. Tyler*).

WINTER INFESTATIONS BY ADULT BLOWFLIES

Three reports were received during January and February of adult bluebottles (*Calliphora erythrocephala*) occurring in sufficient numbers to constitute a serious nuisance, two in domestic premises and one at a bank. In each instance it was found that rats, which had been poisoned in the autumn, had become infested after dying under the floorboards. Larvae had migrated various distances before pupating, some falling through to the rooms below. Winter heating of the buildings induced emergence of the adult blowflies. (*A. A. Green*, *Miss M. J. Kane*).

OVERWINTERING OF HOUSEFLIES

Further visits were made to branches of the large multiple store, particularly to those in which only male houseflies were found in January, 1951. When inspections began in the autumn, there was an equal distribution of the sexes. No flies were observed after December and the findings of the previous year were reversed in that the last surviving flies were eight females.

In October, one branch store had an unusually large number of flies and despite frequent applications of the DDT emulsion used successfully at other branches, little control was obtained. Some of the flies were caught and put in a

breeding cage at the Laboratory. Flies from the first generation were compared with our normal stock and found to be more resistant to DDT. A BHC solution was substituted for the DDT emulsion and all flies were killed within a few days. (*A. A. Green, Miss M. J. Kane*).

RESISTANCE OF HOUSEFLIES TO PYRETHRINS

The normal breeding stock used for insecticidal tests at the Laboratory doubled their resistance to pyrethrins. A comparison, covering 16 generations, was made with flies of normal resistance obtained from another Laboratory. The P.I.L. flies maintained their high resistance over this period and were then discarded as being unsatisfactory insects for standard tests. (*A. A. Green, Miss M. J. Kane, P. S. Tyler*).

INVASION OF A HOUSE BY GROUND BEETLES

In May, 1952, the Laboratory was consulted about the control of a very heavy infestation of one of the Ground beetles (*Harpalus rufipes*) at a large private house. The beetles were invading the whole ground floor, particularly the kitchen where about 600 per night were killed. Although of common occurrence in small numbers in houses it is most unusual to find this beetle entering in such large numbers. No major breeding site was found but all nearby soil was infested with beetles at the rate of at least 50 per square foot.

Bands of pyrethrum concentrate (6·5 per cent in heavy oil) painted round all places of entry to the house gave excellent knock-down and almost complete protection against invading beetles. Large numbers in the soil were killed by the application of a 4 per cent BHC dust. To avoid odour in the house, caused by powder carried on the shoes, 10 per cent DDT dust was used on concrete paths and yards and also gave good control. (*A. A. Green, Miss M. J. Kane*).

CONTROL OF HOUSEHOLD INSECTS

In addition to the advisory work on Clothes moths, Carpet beetles, blow-flies, and Ground beetles already described, a considerable number of enquiries has been dealt with concerning ants, cockroaches, flies, Fur beetles, wasps, hornets, Spider beetles, Biscuit weevils, etc. In some instances inspections have been made and experimental treatments applied. A high level of control has been achieved of the Common Black ant, *Lasius niger*, in domestic premises and of Pharaoh's ant, *Monomorium pharaonis*, in two heavily infested hospitals by the thorough application of a 2 per cent solution of chlordane in a refined kerosene. (Plate I). (*E. A. Parkin, A. A. Green, Miss M. J. Kane*).

VARIATION IN INSECT RESISTANCE

It was reported in 1951 that changes in the resistance to methyl formate of the special stock of the Flour beetle, *Tribolium confusum*, were suspected to be due to very slow and slight changes in the temperature of the breeding room. Continuation of the observations in 1952 revealed that the resistance was varying on an annual cycle and more precise control of the breeding room temperature has eliminated the expected change in resistance during the summer and autumn. The level of resistance of the stock is now being maintained within the statistical limits of homogeneity and the first objective of this research may be regarded as successfully attained. The way has now been opened for investigation of the effect of changes in various factors upon the resistance of the special

stock and some advance has already been made. In the meantime the regular testing of the resistance of the stock is continuing to ensure that the homogeneity of results can be maintained.

In view of the importance of small changes in temperature on resistance experiments have been done to assess the effect of differences of 1°C above and below the standard 25°C. It has been found that beetles kept at 24°C during the 2-week sub-culture period, between removal from the main culture and exposure to the fumigant, were significantly less resistant than the standard beetles (25°C) and that those kept at 26°C were significantly more resistant. Retention of the sub-cultures at 20°C induced a very marked reduction in resistance of the beetles. These results are almost certainly due to the indirect effect of temperature in that it has affected the rate of physiological maturation of the young beetles which increase in resistance and attain a maximum at about the fourth week (see below). Fumigation of beetles kept at a temperature below 25°C is therefore equivalent to exposing beetles of a younger age. Parallel tests with standard beetles kept at 24, 25, and 26°C during the 12-day observation period after fumigation revealed no significant effect of temperature.

Although the cultures are kept in a room maintained at 25°C, the temperature at the centre of a culture during the period of maximum activity of the immature stages may reach about 29°C. The internal temperatures vary with the age of the culture and newly emerged beetles may remain subject to a temperature over 25°C for up to a week before removal to sub-cultures for ageing and maturing. The resistance of beetles cultured in the standard manner was therefore compared with that of beetles obtained from pupae and kept at 25°C throughout their adult life. In accordance with expectation, the beetles from the standard culture which had been exposed for a few days to slightly higher temperatures were a little more resistant.

The resistance of beetles in age groups from 3–4 weeks to 11–12 weeks has been determined. The maximum mean resistance was attained by both sexes in the 3–4 and 4–5-week age groups. Thereafter the resistance declined slowly, though more quickly for females than for males; in the 9–10-week group, the resistance of the females had fallen only to 80 per cent of the maximum level.

Other experiments have shown that there are small but definite differences in resistance between the sexes at the standard age of 2–3 weeks. The females have a slightly greater resistance than the males but tend to be rather more variable.

During the post-fumigation examinations of the thousands of beetles involved in this work, a simple character was discovered by which the sex of *T. confusum* beetles can be determined quickly and certainly from examination of the dorsal surface of the wing covers under a low-powered binocular microscope. A note on this has been prepared for publication.

The attempt to produce a resistant stock of the beetles by exposure of each generation to sub-lethal dosages of the fumigant is progressing slowly. Beetles of five generations have so far been treated but the maximum increase in the level of resistance would be represented approximately by a factor of only 1·4. Although the treatment of this strain will be continued for the present, a second strain will be started for more severe treatment in the hope of accelerating the rate of increase of resistance. (*J. A. Hope, K. G. Gostick*).

FUMIGANTS

During 1952 the Fumigant Section has been concerned in the main with the continuation of projects begun in previous years. A considerable part of the time of some members of the Section has been occupied in the consideration of the special fumigation problems in the Colonies brought to light by the visits to Africa of Mr. Hall and by the many enquiries which have been received as a result of the increasing interest in insect control measures shown by both official and private organizations in the Colonies. Programmes of work have been reviewed and modified to ensure that information is forthcoming which will help in dealing with the fumigation problems in the Colonies as well as those in Britain. There has been some examination of fumigation equipment and methods to enable detailed advice to be sent overseas to countries where there is no body of experience such as exists in Britain in commercial servicing companies and government advisory services.

FUMIGATION OF GRAIN IN SILO BINS

The method of fumigating grain in silo bins by spraying carbon tetrachloride over the grain surface in a full bin has given useful results in routine use by the Infestation Control Division of the Ministry of Agriculture & Fisheries. Occasional failures, as shown by survivals at various depths have, however, been reported. Also, it was realized from the results of the early tests that the concentration-time products obtained in the air space above the grain surface were unlikely to be high enough to give a satisfactory kill of insects which might be present on the exposed walls.

Tests have now been carried out with mixtures of carbon tetrachloride and ethylene dibromide, and of carbon tetrachloride and methyl bromide. Ethylene dibromide was used in the hope of giving an effective treatment of the top few feet of grain and of the air space above the grain. At present, insufficient tests have been done to enable definite recommendations to be made of dosage and permissible temperatures of treatment. It would, however, appear that the addition of, say, 5 per cent by volume of ethylene dibromide to the carbon tetrachloride will give a good control of insects present in the surface layers of grain and in the air space above the grain. Milling and baking tests carried out by the Cereals Research Station, St. Albans, on grain taken from the surface after a test of this type showed no deterioration in quality or taint in the bread.

An early rough test with a mixture of carbon tetrachloride and methyl bromide had given unsatisfactory results (Annual Report, 1948). A small dose of a mixture of equal weights of the two fumigants was used. Later experience with the chlorohydrocarbons confirmed the observations made in other countries that a substantial bulk of liquid fumigant must be applied if satisfactory distribution through a silo bin is to be achieved. Tests have now been carried out using doses of carbon tetrachloride of the same order as are now used in fumigation practice in this country, i.e. about 1 gallon per 12 tons of grain. To the carbon tetrachloride has been added amounts of methyl bromide varying from 3 per cent to 10 per cent by weight. The results of these tests show that at grain temperatures of the order of 60°F or lower, the speed of downward penetration of both components is too low. High concentration-time products of methyl bromide are reached in the upper parts of the bin whilst little or none of this component reaches the bottom. At temperatures

of 70°F or above, a reasonably even distribution of the methyl bromide is rapidly obtained, the carbon tetrachloride acting as a "barrier". A 5 per cent mixture of methyl bromide in carbon tetrachloride would seem to be adequate. Such a mixture should possess a much higher toxicity to insects than carbon tetrachloride alone and its use should increase the probability that an effective treatment will be obtained. A mixture of this type is readily prepared by running methyl bromide from a cylinder into a drum of carbon tetrachloride, the pipe being kept below the surface of the liquid. The vapour pressure and rate of evaporation of the methyl bromide from the mixture are low, and the fumigant can be applied as in the carbon tetrachloride treatment. The precautions which are necessary when applying carbon tetrachloride are adequate when using the mixture in silo bins. (*H. K. Heseltine, G. A. Hamilton, J. B. Waller*).

FUMIGATION OF LARGE BULKS OF GRAIN ON FLOORS

The fumigation in sheds of large bulks of several thousand tons of grain with mixtures of halogenated hydrocarbons has now been put into use on a trial basis by the Infestation Control Division of the Ministry of Agriculture & Fisheries. The Laboratory has carried out tests during a number of these trials. (Plate IV(B)).

The first trials were made with ethylene dichloride and carbon tetrachloride mixed in the proportion 3 : 5 by volume. This was prepared by mixing the commercially available 3 : 1 mixture with an equal volume of carbon tetrachloride. Later trials were made with a mixture of equal volumes of the two compounds. The dose was varied between 1 gallon per 7 tons and 1 gallon per 5 tons. Electrically driven pumps were used to apply the fumigant to the grain surface, the delivery ranging from 5 gallons per minute to 20 gallons per minute. A useful measure of control was obtained in these tests but some survivals have been reported. Difficulties have been experienced in analysing mixtures of carbon tetrachloride and ethylene dichloride in air so that it has not always been possible to obtain reliable figures from the gas-sampling results.

During the course of these trials the need arose to treat infested barley stored in barges by this technique. The Laboratory collaborated with the Infestation Control Division in a comparison of two treatments. In the first, the usual commercial 3 : 1 mixture of ethylene dichloride and carbon tetrachloride was applied to the grain surface at a dose of 1 gallon per 7 tons. After the application the hatches and covers were replaced and the barge left for seven days. The second treatment was similar except that 5 per cent by volume of ethylene dibromide was added to the mixture. The efficacy of the treatments was assessed by gas sampling, the use of test insects, and the examination of the infested grain. As had been anticipated, there was some survival of insects in the surface layers of grain and on the hatch covers in the barge treated with chlorohydrocarbon mixture. This survival appears to have been prevented by the use of the mixture containing ethylene dibromide.

In view of this encouraging result it was therefore decided to test the use of a mixture containing ethylene dibromide in the treatment of large bulks stored on floors. A first trial has recently been carried out as before at a dose of 1 gallon per 5 tons, but with the addition of 2½ per cent by volume of ethylene dibromide to the 1 : 1 mixture of ethylene dichloride and carbon tetrachloride. It is not yet possible to reach a conclusion on the effectiveness of this treatment.

(*W. Burns Brown, H. K. Heseltine, S. G. Heuser, G. A. Hamilton, Miss B. D. Hole, J. B. Waller*).

DISTRIBUTION OF METHYL BROMIDE IN A LARGE STOW OF BAGGED WHEAT FUMIGATED UNDER GAS-PROOF SHEETS

The fumigation of bagged grain with methyl bromide under a covering of gas-proof sheets has been widely practised in Britain for some years (Annual Report, 1950). In Scotland, under the guidance of the Department of Agriculture, Infestation Control, it has become customary to treat very much larger single stacks than have been treated in England. This method of treating large stacks will have important applications in the Colonies and Mr. Hall and Mr. Burns Brown have visited the Glasgow area to study the development of the method there. The opportunity was taken to carry out a limited amount of gas sampling during the fumigation of a large stow arranged by the Department of Agriculture. The stow measured approximately 98 ft. by 40 ft. by 18 ft. (high) (about 70,000 cu. ft.) and contained about 1,200 tons of wheat. The methyl bromide was sprayed into channels left in the top of the stow which was covered by eight large sheets, with edges lapped and rolled in the usual way. Gas samples were drawn from six points inside bags, two of these being buried 3 or 4 bags down from the top of the stow, the others being surface bags on the top or sides of the stow. The results showed a rapid penetration of gas to all these points and suggested that a good distribution was obtained in a few hours. However, to establish that a satisfactory distribution is obtained throughout such a large stow it will be necessary to sample from points deep within the pile. Arrangements have been made with the Department of Agriculture for gas-sampling tubes to be introduced during the building of such stows so that tests can be made if they are fumigated. (*W. Burns Brown, G. A. Hamilton*).

STUDY OF "VACUUM FUMIGATION" TECHNIQUES

In continuing the programme of investigation of different methods of reduced pressure fumigation started last year, a series of tests has been carried out with bagged wheatfeed using methyl bromide as the fumigant. The behaviour of the fumigant during tests was studied by determining gas concentrations in the free space and at different depths within the product. Each test was carried out on a single bag in a chamber of about 1,700 litres capacity in a room controlled at 15°C and 70 per cent R.H.

The technique in which air and fumigant gas are introduced into the evacuated chamber simultaneously through a mixing valve until the pressure approaches atmospheric, was found to be no more effective for this commodity than fumigation at atmospheric pressure. The method in which the fumigant is introduced into the evacuated chamber and the pressure is then immediately brought to atmospheric was shown to be slightly more effective than the atmospheric method. A very much more effective penetration of gas into the bulk was obtained in the method in which the fumigant is introduced into the evacuated chamber and a low pressure (about 7 cm Hg.) sustained over a period.

Small-scale experiments in which methyl bromide gas was allowed to diffuse through a column of wheatfeed from a reservoir maintained at a constant concentration have been carried out at different pressures and it has been shown that when air is removed from the interstitial space fumigant diffuses much

more rapidly through the column. Parallel tests with hydrogen cyanide and carbon dioxide have shown a relationship between rate of penetration and sorption of the gas.

This rapid penetration through the column at low pressures accords with the rapid attainment of high concentrations of fumigant in the bagged wheatfeed during the " sustained vacuum " tests. On releasing the " vacuum " even higher concentrations of gas were obtained in the bulk, further increasing the efficiency of the method. Subsequent tests showed that these high concentrations could be obtained in the centre of the bags by " breaking the vacuum " quite early in the experiment; optimum concentration-time products for a 4-hour period were obtained under the conditions of the tests when the vacuum was released after 1 hour.

" Air washing " techniques in which the chamber is alternatively evacuated and brought to atmospheric pressure at the end of a fumigation period to assist the rapid removal of fumigant have also been evaluated by the gas-sampling method.

Further experimental fumigations have been carried out using bagged whale-meat and bone meal, a comparatively dense and finely divided product containing about 50 per cent protein. The large amounts of methyl bromide sorbed by this commodity make fumigation in a short period at atmospheric pressure impractical since penetration to the centre of the bags is extremely slow. Satisfactory penetration has been obtained using the "sustained vacuum" method. Amounts of methyl bromide combining with the product have been determined. (*W. Burns Brown, S. G. Heuser, R. B. Hedley, Miss C. E. Thomas*).

EFFECT OF TOTAL PRESSURE ON SORPTION OF FUMIGANTS

Amounts of fumigant sorbed by a commodity may be determined by exposure to known concentrations in a closed vessel, the reduction in the free space concentration during the exposure period being measured.

A series of experiments with wheatfeed have been carried out with exposure periods within the range used in the vacuum fumigation tests, i.e., up to 4 or 6 hours. For a finely divided product such as wheatfeed sorption takes place very rapidly during the first hour or two, the total amount sorbed being roughly proportional to the free space concentration. There may be no subsequent increase in sorption or, if the fumigant reacts chemically with the product, the further increase due to this is at a relatively low rate. Sorption isotherms were determined for different exposure periods and from these the rates of sorption at different concentration levels were deduced.

Results have been obtained in this way in tests at atmospheric pressure and at a total pressure of 7 cm Hg. Tests with hydrogen cyanide indicate that, for a given mean concentration level, rate of sorption and amount of gas sorbed are unaffected by total pressure. Tests with methyl bromide are in progress. (*S. G. Heuser, R. B. Hedley*).

PRELIMINARY TRIALS WITH ETHYLENE OXIDE FOR THE STERILIZATION OF BOOTS

At the request of the Director, Army School of Hygiene, trials were made to determine whether ethylene oxide was likely to prove of value in the sterilization of boots as a means of reducing the spread of organisms causing " Athlete's Foot". The culturing and identification of fungi in test materials was carried out

the Mycological Reference Laboratory, London School of Hygiene and ropical Medicine and treatment of the materials in the Fumigant Section, Pest nfestation Laboratory. Tests were made with infected scales of skin tissue and nfected boots. A report of the tests has been prepared by the Fungicide and nsecticide Research Coordination Service, Agricultural Research Council, hich organized the tests. (*W. Burns Brown, S. G. Heuser, R. B. Hedley*).

OXICITY OF FUMIGANTS TO INSECTS

The series of tests started last year and described in the Annual Report for 951 on the toxicity of different fumigants to about ten kinds of test insect at)°, 15° and 25°C has been continued. In all, nine fumigants have now been sted in this way. These are carbon tetrachloride, trichlorethylene, perchlor-hylene, ethylene dichloride, methallyl chloride, methyl bromide, ethylene ibromide, hydrogen cyanide and chloropicrin. The main object of these tests to draw attention at an early stage to what are likely to be, from the point of iew of toxicity, the chief features of the practical performance of the fumigants n question. Now that a reasonable number of fumigants has been tested it is ossible to attempt to make some distinction between them and also between st insects. Some of these differences may be briefly outlined by reference to hree of the fumigants tested.

Some idea of the magnitude of the differences in estimates of dosage for 99.9 er cent kill of different kinds of test insect when treated by one fumigant may rst be obtained from the data as a whole. Differences of 2 to 3 times are fre-quent, and of around 5 times not uncommon, but differences of greater than 10 mes are exceptional. In general, differences between different stages of the ame species are as great as those between the same stage of different species. ome effects on toxicity associated with temperature were described last year nd it is very evident that no simple generalization in terms of dosage for 99·9 er cent kill is possible.

The differences in resistance to *methyl bromide* of different species and stages f test insect have been found to be smaller than with the other fumigants tested. Methyl bromide shows a definite decrease in toxicity with decrease in tempera-ure. Also the rate of increase in kill with increase in dose is rapid. These results uggest that with this fumigant at each temperature a concentration-time pro-uct can be used for general purposes which will ensure a complete kill yet will ot be greatly in excess of the minimum needed in particular circumstances. 'ery low kills may result from a relatively small reduction in dosage below the ninimum required. Particularly detailed toxicity data and knowledge of the umigation conditions would be necessary in order to estimate the dose required nore exactly.

The differences in resistance to *carbon tetrachloride* of different species and stages f test insect are greater than with methyl bromide and a slower rate of increase n mortality with increase in dose is found. A very substantial kill of all stages of ny one species can be obtained at doses well below that required for a complete ill. It follows that it is more difficult than in the case of methyl bromide to rrive at a concentration-time product for general use which gives certainty of a omplete kill of all species present but which is not sometimes greatly in excess f the minimum required. Concentration-time products in mg. hr. per litre, f about 40,000 for 99·9 per cent kill and of 20,000 for 99·0 per cent kill of pre-dult stages of *Calandra granaria* at 10°C were estimated. The question arises

whether the difference between a 1 per cent and a 0·1 per cent chance of survival in a practical fumigation justifies such an increase in dose and whether in some cases a satisfactory control could be obtained with yet higher chances of survival.

Results with *ethylene dibromide* show unusually large differences in the resistance of different species of insect. In the experiments with adult insects ethylene dibromide also produces an unusually large progressive increase in mortality as the insects are held for observation after fumigation. This occurs even at 25°C and samples of adults the majority of which appear at first to have been unaffected by the fumigant may show a complete mortality if held at this temperature for ten days or a fortnight. For this fumigant the time after fumigation when mortality is finally assessed and the identity of the species present are likely to prove the first considerations when determining the concentration-time product required.

Further tests have been carried out on *Calandra granaria* adults with ethylene dichloride and carbon tetrachloride to determine the effect on mortality of changes of temperature after fumigation. The effects produced differ for these two fumigants and vary among the different kinds of test insects.

These results, and others obtained in the last few years have all emphasized the number and variety of factors which contribute to differences in toxicity and these are by no means fully explored. The question of how closely laboratory data on a particular kind of test insect will relate to practical work has been increasingly complex.

Some quantitative estimate of this is needed and although the amount of data so far obtained does not permit of any but very obvious comparisons these do, however, show that there are characteristic features of the toxicity of different fumigants. These characteristics can be related to their advantages and disadvantages in different types of fumigation. They also indicate differences between fumigants in what are, for the purpose of estimating the required dose from toxicity data, the most important features of the particular circumstances of practical treatments.

In answer to specific requests some tests have been made on the toxicity of carbon dioxide. At 25°C and 70 per cent R.H. exposure to 50 per cent CO_2 for a week gave a complete kill of *T. castaneum* eggs. At 30°C and 70-80 per cent R.H. exposure to 15 per cent CO_2 for a week was quite ineffective in controlling *C. oryzae*, *T. castaneum*, and *R. dominica* adults and *T. granarium* larvae (*W. Burns Brown, S. G. Heuser, Miss E. M. Reynolds, Miss B. D. Hole, R. E. Hedley, Miss M. F. East, Miss C. E. Thomas*).

BIOCHEMISTRY

Insecticide Biochemistry in Relation to Foodstuffs

NATURE OF METHYL BROMIDE RESIDUES IN FUMIGATED WHEAT

Work has continued on the nature of the chemical reactions between wheat and methyl bromide under the conditions of fumigation. It had earlier been shown that about half of the residual methyl bromide was present as methyl sulphonium, methoxy, and thiomethoxy derivatives. The remaining half appeared to be present as N-methylated derivatives of the protein (gluten

raction. Work during the year has been directed at characterizing and identiying the N-methylated derivatives. A milled sample of wheat, grown in sand ulture containing S^{35}-labelled sulphate so that methionine, cystine, etc., vere already labelled, was exposed to C^{14}-labelled methyl bromide.

Prepared samples of wheat gluten of different moisture contents were simiarly exposed. Gluten prepared from the exposed wheat, and the exposed luten samples were hydrolysed in hydriodic acid to remove labile methyl roups. The hydrolysates were examined by means of starch column and aper chromatography. So far the results indicate that N-methylation has ccurred selectively with the significant formation of only one or two derivtives believed to be from basic amino acids. These N-methyl compounds re not, apparently, derived from the sulphur-containing amino acids (e.g. nethionine) because of the lack of coincidence between the S^{35}- and C^{14}-adioactivity in the chromatograms. (*F. P. W. Winteringham, A. Harrison, C. A. Bridges*).

UTRITIONAL AND TOXICOLOGICAL SIGNIFICANCE OF METHYL BROMIDE FUMIGATION

Work on the possible effects of methyl bromide on vitamins of the B group n collaboration with Drs. K. M. Clegg and E. Kodicek of the Dunn Nutritional Laboratory has been completed and written up for publication. Preliminary xperiments with ethylene oxide have shown that this substance reacts chemiclly with nicotinic acid and nicotinamide in solution. Further experiments vill be made on the reactions in wheat under fumigation conditions.

Methyl methionine sulphonium bromide (M S B), representing the principal ulphur compound formed in methyl bromide-fumigated wheat has been preared at the Pest Infestation Laboratory and examined for possible mammalian oxicity by Dr. J. Pace of the Cereals Research Station, St. Albans. Weanling ats were fed on formulated casein diets which were respectively methionine-nd M S B-deficient (control), methionine-supplemented, and, M S B-supplenented. The rats grew more rapidly on either of the supplemented diets than n the control which suggested that the growing rat is able to utilize M S B as substitute for methionine. With the micro-organism *Leuconostoc mesenteroides* (which had been successfully used for bio-assaying the toxic methionine ulphoximine produced in "Agenized" flour) M S B failed completely to replace nethionine in the medium. No evidence of acute toxicity was observed when ither rats or *L. mesenteroides* was used. (*F. P. W. Winteringham, S. E. Lewis, A. Harrison*).

Insecticide Biochemistry in Relation to Insects

CETYLCHOLINE-ESTERASE ACTIVITY IN INSECTS

In an attempt to understand better the function of cholinesterase and the ature of chemical mediation in synaptic and neuromuscular transmission n insects the cholinesterase activity over the whole life cycle of certain species s being determined. This has been completed for *Lucilia sericata*, the optinum pH for acetylcholine-esterase activity *in vitro* having been found to be ·8. The low esterase activity in *Tenebrio molitor* has been confirmed. The ossible inhibition by a natural inhibitor is being investigated by studying he effects of *Tenebrio* extracts on the esterase prepared from *Lucilia*. (*S. E. Lewis, Miss M. K. Winckler*).

EFFECTS OF METHYL BROMIDE ON INSECT ENZYMES

The Thunberg technique using methylene blue as a hydrogen acceptor has been used for measuring the spontaneous dehydrogenase activity in muscle and nervous tissue preparations from normal and methyl bromide-poisoned cockroaches and *Calliphora* larvae. There was no evidence of inhibition by methyl bromide. The effects of methyl bromide on the oxygen uptake of *Calliphora* larvae have been determined manometrically in the Warburg apparatus. At a dose level of 4 mg of methyl bromide per litre for 14 h at 25°C the larvae developed symptoms three hours after exposure. They sometimes survived to pupation but none ever emerged as adults. Treated larvae appeared to have a higher rate of oxygen uptake than controls but further experiments with chopped larvae showed that the effect varied with age, was most pronounced at 3–4 days, and was connected with melanin formation which also appeared to be inhibited by methyl bromide. In further experiments there was no evidence of general esterase inhibition in methyl bromide-treated larvae. (*S. E. Lewis, Mrs. B. G. Patterson*).

HISTOLOGICAL DISTRIBUTION OF METHYL BROMIDE IN *Calliphora* LARVAE

Larvae were exposed to low concentrations (1 and 5 mg/litre) C^{14}-labelled methyl bromide for a period of 10 h at 25°C. Tissues were fixed and dehydrated by the Altmann-Gersh technique, embedded in paraffin wax (in vacuo), sectioned and autoradiographs prepared using nuclear track emulsion. The results indicated a concentration of radioactive carbon (presumably as methyl groups) in muscle tissue. A second observation was that a high proportion of the carbon-14 in the tissue was water-soluble as evidenced by leaching effects in the autoradiographs. This was confirmed by extracting some of the tissue. The solubility would be accounted for by the direct reaction between the absorbed methyl bromide and the known high free amino acid content of the insect haemolymph with the formation of water-soluble methylated derivatives. (*Miss P. M. Loveday*).

ABSORPTION AND METABOLISM OF DDT BY NORMAL AND DDT-RESISTANT HOUSEFLIES

The work on this subject has been directed to filling in some gaps in the earlier data, mainly on the absorption at high dose levels of topically-applied DDT and on the effects of temperature on the enzymic dehydrohalogenation *in vivo*. A radioactive bromine analogue of DDT was used as an indicator in all the work. The general conclusions to date are :—

DDT resistance in houseflies is not due to lack of penetration of the insecticide through the integument.

The optimum temperature for DDT dehydrohalogenation by resistant flies is about 40°C.

Susceptible as well as resistant flies are capable of decomposing absorbed DDT provided the dose absorbed is sufficiently low.

There is evidence of at least two different mechanisms of housefly resistance to DDT, one linked with dehydrohalogenation, the other not. (*F. P. W. Winteringham, A. Harrison, Miss P. M. Loveday, R. G. Bridges*).

EFFECT OF INSECTICIDES ON THE PHOSPHORUS METABOLISM OF INSECTS

Studies have continued on the effect of insecticides and fumigants on some of the better understood metabolic pathways in insects. For this purpose

adult houseflies have been fed on a mixture of dextrose and water containing "carrier-free" P^{32}-labelled orthophosphate. In this way flies have been obtained in which the phosphorus-containing intermediates of carbohydrate metabolism are uniformly labelled. The normal distribution of these intermediates in muscle tissue has been determined by combined tracer-paper chromatography techniques. Experiments are in progress to determine the disturbances in glycolysis due to DDT, pyrethrins, methyl bromide and hydrogen cyanide. (*F. P. W. Winteringham, G. C. Hellyer*).

METABOLISM OF PYRETHRINS ABSORBED BY ADULT HOUSEFLIES

Preliminary studies were made in the Insect Toxicology Laboratory of the University of California. For this purpose a sample of C^{14}-biosynthetically labelled pyrethrins was used which was generously donated by the Gulf Research and Development Co. of Pittsburgh, Pa., U.S.A. The results, which can only be regarded as tentative at this stage, indicated that the pyrethrin molecule is modified enzymically *in vivo* by the adult housefly. When the pyrethrin synergist, piperonyl cyclonene, and the labelled pyrethrins were applied simultaneously to the flies there was no evidence of modification and the flies succumbed more rapidly. This suggests that the modification is a defensive rather than a lethal mechanism and that the function of the synergist is to inhibit this normal defensive mechanism. On this basis it is predicted that allethrin, which is not effectively synergized by piperonyl cyclonene, should be found to be more stable *in vivo* than the natural insecticide. It is proposed to test this point. (*F. P. W. Winteringham*).

Miscellaneous Experimental Work

RADIOACTIVE WHEAT

To facilitate certain studies on the nature of fumigant residues in wheat further quantities of wheat grain have been successfully harvested from sand cultures in which S^{35}-labelled sulphate was the sole source of plant sulphur. It was found that a level of S^{35}-activity of 7 millicuries in the 2 litres of nutrient salts circulated over the root system of the plants seriously inhibited growth and none of the plants reached maturity. Plants grown in 1 and 2 millicurie levels reached maturity. (*Miss P. M. Loveday, G. C. Hellyer*).

LABELLED BENZINE HEXACHLORIDE

A small quantity of the gamma-isomer of hexachlorocyclohexane (BHC) labelled with Cl^{36} has been successfully prepared and is available for further biochemical studies. (*A. Harrison*).

PAPER CHROMATOGRAPHY OF THE PYRETHRIN-TYPE INSECTICIDES AND THEIR DERIVATIVES

For the purpose of studying the metabolic fate of the pyrethrin molecule in insects a method was developed for separating completely the natural monocarboxylic and dicarboxylic pyrethrin esters, synthetic allethrin and the corresponding free acids and alcohols. The esters may be separated by reversed phase paper chromatography, using paper impregnated with petroleum jelly or "Vaseline." The free acid and alcohol groups may be separated from each other and from the esters by a simple two-solvent system of paper chromatography. A sensitive technique for the detection of all these materials was

developed and consisted in oxidation of the unsaturated linkages with neutral permanganate followed by spraying with benzidine acetate. (*F. P. W. Winteringham*).

BIO-ASSAY OF ACETYLCHOLINE

As part of the work on the problems of chemical mediation in the neuromuscular system of insects a method of assaying acetylcholine by the contraction of eserinized frog rectus muscle has been tested and found to be suitable. (*S. E. Lewis, Mrs. B. G. Patterson*).

CARTESIAN-DIVER MICRORESPIROMETRY

The construction of the Cartesian-Diver microrespirometer assembly has been completed and is available for application to the respirometry of very small samples of insect tissue. (*K. S. Fowler*).

LIBRARY

The Laboratory Library now contains 680 books and 3,850 pamphlets, mostly reprints from scientific and technical journals, in addition to a large number of other reports, patents, maps, etc.

Acquisitions during 1952 included 84 books, 408 reprints, and 238 reports, etc.

136 periodicals (including a number in duplicated form) are taken and a further 71 are seen regularly on loan. All these are read and appropriate papers are indexed. Articles of interest are drawn to the attention of the research staff if they occur in journals which are not normally scanned by the individuals concerned. This service has proved very valuable. (*Miss H. C. N. Turnbull, Miss S. G. Rawle, Miss C. M. Barber*).

PHOTOGRAPHY

The Laboratory possesses a small but highly efficient photographic unit which covers work in the field, e.g. on full-scale trials, as well as in the laboratory, where photographs are made of scientific apparatus and techniques, biological material including insects and fungi, and the reproduction of microscopical preparations such as autoradiographs.

In addition the unit photographs reprints and scientific articles on the many occasions when these cannot be retained in the Library. (*J. H. Hammond, Miss A. M. Stott*).

PEST INFESTATION LABORATORY,
London Road,
Slough, Bucks.
January, 1953.

G. V. B. HERFORD,
Director of Pest Infestation Research

APPENDIX I

Papers Published in 1952

1. Brown, W. B. The Benzidine Acetate-Copper Acetate Test for Hydrogen Cyanide. *Chem. Ind., Lond.*, 1952, (6), 124-126.
2. Coombs, C. W. and Woodroffe, G. E. Two Species of *Cryptophagus* (Col., Cryptophagidae) new to Britain. *Ent. mon. Mag.*, 1952, **88** (1062), 259-260.
3. Green, A. A. The Blowfly Problem. *J. R. sanit. Inst.*, 1952, **72** (5), 621-626.
4. Herford, G. V. B. The Infestation of Stored Foodstuffs by Insects. *J. Sci. Fd. Agric.*, 1952, **3** (1), 1-11.
5. Hewlett, P. S. Piperonyl Butoxide as a Constituent of Heavy-Oil Sprays for the Control of Stored Product Insects. II. The Effect of Piperonyl Butoxide on the Toxicities of Allethrin, DDT, and BHC, and on the Joint Toxicity of BHC and Pyrethrins to *Tribolium castaneum*. *Bull. ent. Res.*, 1952, **43** (1), 21-32.
6. Hewlett, P. S. Comparison of Insecticide Activation. *Nature, Lond.*, 1952, **169** (4307), 844-845.
7. Hewlett, P. S. and Plackett, R. L. Similar Joint Action of Insecticides. *Nature, Lond.*, 1952, **169** (4292), 198-199.
8. Howe, R. W. Experiments on the Use of Pyrethrum Powder as an Admixed Dust in the Tropics. *Pyrethrum Post*, 1952, **2** (4), 4-6.
9. Howe, R. W. Note on the Egg Output of *Attagenus megatoma* (F.) (=*piceus* (01.) (Col. Dermestidae). *Ent. mon. Mag.*, 1952, **88** (1053), 40-41.
10. Howe, R. W. Entomological Problems of Food Storage in Northern Nigeria. *Bull. ent. Res.*, 1952, **43** (1), 111-144.
11. Howe, R. W. The Biology of the Rice Weevil, *Calandra oryzae*, (L.), *Ann. appl. Biol.*, 1952, **39** (2), 168-180.
12. Howe, R. W. Notes on the Biology of *Trogoderma versicolor* Creutz (Col., Dermestidae). (Resistance to Starvation and Reaction to Cracks shown by Larvae ; Resistance to Heat and Egg Output of Adults). *Ent. mon. Mag.*, 1952, **88** (1059), 182-184.
13. Howe, R. W. Miscellaneous Experiments with Grain Weevils. *Ent. mon. Mag.*, 1952, **88** (1062), 252-255.
14. Howe, R. W. and Burges, H. D. Studies on the Beetles of the Family Ptinidae. VII. Biology of Five Ptinid Species found in Stored Products. *Bull. ent. Res.*, 1952, **43** (1), 153-186.
15. Howe, R. W. and Burges, H. D. A Note on the Survival of *Alphitobius laevigatus* F. (Col., Tenebrionidae) in Warm Dry Conditions. *Ent. mon. Mag.*, 1952, **88** (1058), 160-161.
16. Howe, R. W., Hayward, L. A. W. and Cotterell, G. S. Control Measures in 1948-50 against Insects attacking Groundnuts stored at Kano, Northern Nigeria. *Bull. ent. Res.*, 1952, **43** (2), 259-279.
17. Robertson, P. L. Cheese Mite Infestation. An Important Storage Problem. *J. Soc. Dairy Tech.*, 1952, **5** (2), 86-95.

18. STEEL, W. O. and HOWE, R. W. A New Species of *Laemophloeus* (Col., Cucujidae) associated with Stored Products. *Proc. R. ent. Soc., Lond., B.*, 1952, **21** (5/6), 86-88.
19. WINTERINGHAM, F. P. W. Some Aspects of Insecticide Biochemistry. *Endeavour*, 1952, **11** (41), 22-28.
20. WINTERINGHAM, F. P. W. Metabolism of DDT by Resistant Houseflies. *Nat. Acad. Sci.* (*U.S.A.*), Publication No. 219, Washington D.C., 1952, 61.
21. WINTERINGHAM, F. P. W. Separation and Detection of Pyrethrin-Type Insecticides and their Derivatives by Reversed Phase Paper Chromatography. *Science*, 1952, **1161** (3017), 452-453.
22. WINTERINGHAM, F. P. W., HARRISON, A. and BRIDGES, R. G. Radioactive Tracer-Paper Chromatography Techniques. *Analyst*, 1952, **77** (910), 19-28. (And in *Nucleonics*, 1952, **10**, 52-57.)
23. WOODROFFE, G. E. The Biological Origin of our Domestic Insect Pests. *Biology*, 1952, **18** (1), 30-34.

APPENDIX II

Staff of the Pest Infestation Laboratory 1952

Director of Pest Infestation Research : G. V. B. Herford, O.B.E., M.Sc.
Assistant Director : E. A. Parkin, Ph.D., M.Sc., D.I.C.
Colonial Liaison Officer : D. W. Hall, B.Sc.
(*Senior Scientific Officer*)

BIOLOGY SECTION

Principal Scientific Officer : M. E. Solomon, M.Sc.
Senior Scientific Officers : R W. Howe, B.Sc., A.R.C.S. ; G. E. Woodroffe.
Scientific Officer : C. W. Coombs, M.Sc.
Experimental Officers : A. M. Cunnington ; Mrs. G. Blake, B.Sc.
Assistant Experimental Officer : H. D. Burges, B.Sc.
Assistants (*Scientific*) : B. J. Southgate ; Miss B. E. Adamson ; Miss S. M. Nightingale ; Miss R. Borrett ; Miss M. Jackson ; Miss J. E. Currie ; *K. I. Street.

FUMIGANT SECTION

Principal Scientific Officer : W. Burns Brown, M.Sc., F.R.I.C., A.R.C.S., D.I.C.
Senior Experimental Officer : H. K. Heseltine.
Experimental Officers : S. G. B. Heuser ; Miss E. M. Reynolds.
Assistant Experimental Officers : Miss B. D. Hole ; *G. A. Hamilton ; R. B. Hedley, B.Sc.; †J. B. Waller.
Assistants (*Scientific*) *:* Miss M. F. East ; Miss C. E. Thomas.

INSECTICIDE SECTION

Senior Principal Scientific Officer : E. A. Parkin, Ph.D., M.Sc., D.I.C.
Senior Scientific Officers : P. S. Hewlett, B.Sc. ; J. A. Hope, B.Sc. ; B. P. Moore, Ph.D., D.Phil., B.Sc.
Senior Experimental Officer : A. A. Green.
Scientific Officer : Mrs. P. J. Maycock, B.Sc.
Assistant Experimental Officers : G. T. Bills, B.Sc. ; A. Simmonds ; K. G. Gostick ; Miss K. D. Lambe, B.Sc. ; Miss M. A. Cant, B.Sc.
Assistants (*Scientific*) *:* Miss M. J. Kane ; Miss D. G. Blackman ; Miss C. Belcher ; P. S. Tyler.

BIOCHEMISTRY SECTION

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Senior Scientific Officer : S. E. Lewis.
Senior Experimental Officer : A. Harrison.
Experimental Officer : K. S. Fowler, B.Sc., A.R.I.C.
Assistant Experimental Officers : R. G. Bridges ; Miss P. M. Loveday, B.Sc. ; Mrs. B. G. Patterson, B.Sc. ; Miss M. K. Winckler ; G. C. Hellyer.
Assistant (*Scientific*) *:* Miss P. M. Heaton.

FOOD STORAGE

Principal Scientific Officer : T. A. Oxley, B.Sc., A.R.C.S.
Senior Scientific Officer : Miss M. B. Hyde, M.Sc.
Assistant Experimental Officers : G. Ayerst ; ‡J. P. Heslop, B.Sc. ; R. W. Disney.
Assistant (Scientific) : D. Budd.

PHOTOGRAPHY

Senior Photographer : J. H. Hammond, A.R.P.S.
Assistant Photographer : Miss A. M. Stott.

GLASS BLOWER

Senior Assistant (Scientific) : A. E. Broughton.

LIBRARY

Experimental Officer : Miss H. C. N. Turnbull, M.A.
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Clerical Officer : Miss B. A. Kent.

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Temporary Clerk III : Mrs. B. D. Bell.
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Labourer : *C. G. Tubb.
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* Resigned in 1952.
† On National Service.
‡ Treasury Bursary.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

REPORT OF THE PEST INFESTATION RESEARCH BOARD

WITH THE REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH

FOR THE YEAR 1953

LONDON: HER MAJESTY'S STATIONERY OFFICE
1954

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Charles House, 5-11, Regent Street,
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* Resigned during 1953

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CONTENTS

REPORT OF THE PEST INFESTATION RESEARCH BOARD FOR THE YEAR 1953

To the Lords of the Committee of the Privy Council for Scientific and Industrial Research.

MAY IT PLEASE YOUR LORDSHIPS,

WE, the Pest Infestation Research Board, beg leave to present a report on our proceedings during the year 1953. The Report of the Director of Pest Infestation Research for the same period is appended.

There have been several changes of membership of our Board during 1953, the following members and assessors retired: Prof. G. R. Cameron, Dr. C. B. Williams, Mr. J. E. Cummins, Dr. G. A. C. Herklots, Lt. Col. Pasricha, Dr. W. J. Arroll. The following new appointments were made: Dr. J. M. Barnes, Dr. W. J. Hall, Mr. D. Rhind, Dr. S. Krishna and Mr. J. E. C. Coventry.

We have held three meetings during the past year, two of which were at the Laboratory, when we were able to inspect the research work in progress.

We are particularly glad that it has been possible, through a " Five Year Plan," to make provision for some expansion in the resources of the Department as a whole. Having in mind the importance to this and other countries of the prevention of losses to stored foodstuffs, we earnestly hope that due regard will be given to the need for expanding the work of the Pest Infestation Laboratory.

It is encouraging that the liaison with the Colonies, mentioned in our Report for 1952 as a promising development, is expanding with great rapidity. There is no doubt that the Laboratory can be of very great assistance in this important field, and we recommend that this side of the Laboratory's work should be strengthened.

Liaison with the Infestation Control Division of the Ministry of Agriculture and Fisheries continues to be close and effective, and we draw attention to the investigation in the " field," of methods in current use for the control of one of the important pests of stored grain, the moth *Ephestia elutella*. This work has been undertaken at the request of the Infestation Control Division.

It is a matter of satisfaction that the Laboratory is able to maintain a considerable amount of " background " research, in support of the more applied and *ad hoc* work and it is gratifying to be able to record that a Civil Service Research Fellow, Miss P. L. Robertson, is now at the Laboratory studying species variation and allied problems in mites.

We are glad to report the completion of a new building to house the Biochemistry Section of the Laboratory. This was opened in November by Sir Ben Lockspeiser, whom we were very pleased to welcome to our Board meeting on the same day. It is our hope that this building will be the first of several much larger buildings to provide adequate accommodation for the remaining

sections of the Laboratory, the need for which we have already stressed.

We draw attention below to certain items of current research, selected to illustrate the diverse nature of the problems under investigation at the Laboratory. We are particularly glad that it has been possible to undertake some work on a larger scale than heretofore. There is clearly a need for this side of the Laboratory's activities to be expanded, especially as a background to advisory work in the Colonies. We would instance the need for the closer scientific study of the storage of grain in air-tight underground pits.

IMPREGNATION OF SACKS WITH INSECTICIDE FOR THE PROTECTION OF FOODSTUFFS

Further tests have been undertaken during 1953, of the effectiveness of impregnating sacking with a mixture of pyrethrins and piperonyl butoxide. In two series of experiments small " sacklets," suitably impregnated and containing cereals were exposed to attack by Flour beetles. One set of sacklets was stored in the dark, and one set was exposed to sunlight or diffused daylight. The sacklets stored in the dark, without change of foodstuff, retained their insecticidal properties for about 9 months, while those exposed to light lost their toxicity after about 6 months. Experiments on a larger scale, using 2-cwt. sacks, gave results in good agreement with the tests on sacklets.

CONTROL OF INSECTS IN WAREHOUSES

After completion of the practical work on the control of blowflies in slaughter-houses, the same Laboratory team has been investigating, at the request of the Infestation Control Division of the Ministry of Agriculture and Fisheries, the control of the so-called Cacao moth in a " mixed " London warehouse. This insect has recently been responsible for an increasing number of infestations during the last few years. A comparison was made of different spraying techniques, one floor of the warehouse being devoted to each.

The conclusions drawn from the first season's work suggest that:

(a) The officially recommended treatment, if conscientiously applied, is satisfactory for the protection of bagged goods against this insect. The treatment is, however, laborious and somewhat complicated.

(b) An alternative treatment involving the use of a portable machine producing a dense mist of insecticide can give equally good protection, and is more convenient to apply.

AIRTIGHT STORAGE OF GRAIN

The large scale experiment foreshadowed in our Report for 1952 was started in August 1953 and is still in progress. It is hoped that the results of the experiment may be available for report next year.

RAPID DETERMINATION OF THE MOISTURE CONTENT OF GRAIN

Reference was made in the Director's Report for 1952 to the need for a device for the very rapid determination of grain moisture content. This need is particularly felt in certain Colonial territories, where grain is bought by the Government only if it contains less than a certain specified percentage of water.

Portable equipment has now been designed, and a prototype built, which seems to fulfil the requirements satisfactorily. This device uses the principle of measuring the electrical resistance between electrodes pushed in to the grain. Although this principle is not new its application for this purpose and the preci-

arrangement of the electrodes form at present the subject of a patent application. It is hoped that commercial production of this instrument can be arranged as soon as protection has been obtained.

Your Lordships will be aware, from our previous reports, of the wide range of subjects covered by the research programme of the Laboratory, including as it does research in entomology, insect and plant physiology, mycology, physics, chemistry and radio-chemistry in so far as these fall within the scope of the control of pest infestation. There is no other Laboratory of comparable size which is devoted to the study of the protection of stored products, and we are glad to have evidence that the Laboratory is already achieving an international reputation. It is interesting to note that overseas visitors to the Laboratory during 1953 came from 33 different countries.

F. R. HORNE,
Chairman

28*th January*, 1954

REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH FOR THE YEAR 1953

GENERAL

For the benefit of those previously unacquainted with the Laboratory the objectives of the work may be summarized as follows: " The study of the biology and control of insects and mites infesting stored foodstuffs and of certain domestic insects, and the investigation of improved methods for storing grain and certain other commodities."

1953 has been a year of steady progress in all sections of the Laboratory, as is indicated by the list of 29 papers published during the period.

In the main, the principal lines of research have continued unchanged from the previous year; certain investigations have been completed, however, notably the work on the infestation of slaughterhouses by blowflies, and the study of the interaction of wheat protein with the fumigant methyl bromide. Some new lines of work have been started, for example, a study of the practical control of the Cacao moth in a London warehouse, and an ecological investigation of the beetle *Trogoderma granarium*, a pest of maltings in this country, and one which causes very great damage to stored foodstuffs in certain Colonial countries.

The link between the Laboratory and the Colonies has been greatly strengthened during 1953, largely through the activities of the Colonial Liaison Officer.

There is no doubt that there is work of the highest importance to be done in relation to the conservation of food in the Colonies, whether it be for famine reserves or the improvement in the quality of export crops. Now that interest has been aroused, the requests for technical advice and assistance coming from Colonial territories are over-taxing the capabilities of the existing staff at the Laboratory.

In order to cope more effectively with these requests for assistance, it has been suggested that a small pool of stored products entomologists might be set up in Britain and attached to this Laboratory. The members of the pool would work on specific problems in the Colonies, probably on some repayment basis, returning home when their particular task had been completed. The reaction of Colonial territories to this proposal is being sought by the Colonial office.

The new Biochemistry block has been completed and was formally opened by Sir Ben Lockspeiser in November. The additional space now available, and the excellent design and finish of the laboratories are greatly facilitating the work of this section.

Plans are in active preparation for the eventual replacement of all existing temporary buildings by properly designed laboratories.

The Director attended the first meeting of the Stored Products Working Party of the European Plant Protection Organization, held in Brussels in July. Dr. Parkin (Assistant Director) has attended meetings in Paris and Brussels of

an international committee concerned with the standardization of mothproofing materials.

During the year under review Mr. A. A. Green has been awarded the M.B.E. and Mr. W. Burns Brown and Miss M. J. Kane have received Coronation Medals.

Mr. R. W. Disney has been awarded a Treasury Bursary and is studying for a special Honours degree in Physics at London University.

BIOLOGY

The main themes of work of the Biology Section may be summarised in three headings as follows:

1. Determination of the habits and distribution of pests and analysis of their behaviour.

2. Determination of the rates of increase of pests under various conditions.

3. Determination of the limits of temperature and humidity for the development or survival of each species, and of the rates of extermination by extreme conditions.

Of the items reported below, the survey of insects in a ship's holds comes under the first heading, as does some of the work on Carpet beetles and the study of Khapra beetle populations in maltings. The bulk of the remaining items falls under heads 2 or 3, the exceptions being the work on the fumigation of mites and on their hypopus stage, the study of the theory of grain heating, the work on the taxonomy of *Cryptophagus* and on the embedding of insect specimens in plastic blocks.

The only items which are not continuations of work reported last year are those dealing with the theory of grain heating and with the fumigation of mites.

A good deal of work has been carried out in co-operation with the Infestation Control Division of the Ministry of Agriculture and Fisheries. In collaboration with Dr. J. A. Freeman, of the Division, Mr. R. W. Howe has prepared a paper, based on the reports of their Inspectors, dealing with the insects imported on produce from W. Africa. Many Inspectors and Entomologists of the Division have sent in samples of populations of *Laemophloeus* spp. or *Cryptophagus* spp. for identification by members of the Biology Section making a study of these insects, and some have sent samples of mite infestations containing *Glycyphagus* or hypopi of *Tyroglyphus farinae*. This material has contributed greatly to the progress of the work.

At the request of the Colonial Liaison Officer, several members of the Section have examined a series of samples of infested material from Africa and identified the insects or mites.

A certain number of enquiries, chiefly from members of the public, have been dealt with by letter. The bulk of these have dealt with the common Carpet beetle; towards the end of the year the advisory work on this pest was taken over by the Insecticide Section.

Late in the year, Miss P. L. Robertson returned to the Laboratory on a Civil Service Research Fellowship, after two years at the Zoology Dept., Cambridge. She will continue her investigations on cheese mites and related species. The main themes of this work are the interactions and succession of the species associated with cheese, and the comparative morphology and systematics of the genus *Tyrophagus*.

Most of the laboratory work in past years has been conducted at constant temperatures, so that the results have often been difficult to apply to storage conditions in which the temperature fluctuates. "Field" experiments, like those described on overwintering, do something to close the gap, but experiments in which the temperature fluctuations are controlled are also essential. For this purpose, a thermostat has been modified to give a controlled daily cycle of temperatures. This should be useful, for example, in examining the ability of various species to survive repeated short exposures to unfavourable conditions, an ability which often plays a great part in determining the limits of their distribution.

RESIDUAL POPULATIONS IN A SHIP

In continuation of the study of insects established in the less accessible parts of storage places, another survey of a ship's holds has been made.

The construction of this ship was such that an appreciable infestation might have been expected. Thus some holds had a false bottom of wood, separated from the tank tops beneath by a gap of up to two inches; also the bilges were readily accessible. Both these are well-known sites for residual infestations in ships. Unfortunately heavy rainfall had flooded many of these areas and made them unfit for sampling. Most of the bilge compartments which were not flooded contained little food residue and few insects.

The numbers of insects found in other parts of the ship were not large and most of these were found in open sites—under dunnage and on ledges at the junctions of hull frames and girders—rather than in concealed retreats such as inside pipe casings. The former would, presumably, have been cleaned had the ship been used again and so the residual infestation would have been slight.

Of the insects found, some were distributed fairly generally throughout the holds; these included the Rust-Red Flour beetle (*Tribolium castaneum*), the Merchant Grain beetle (*Oryzaephilus mercator*), and the Cadelle beetle (*Tenebroides mauritanicus*). Others, such as the Dried Fruit beetle (*Carpophilus dimidiatus*) and the Foreign Grain beetle (*Ahasverus advena*), were restricted to a few sites. (*C. W. Coombs, G. T. Bills*).

OVERWINTERING OF PESTS

The ability or inability of pests to survive the winter in unheated buildings is often a major factor affecting their prevalence and their importance as pests in Britain. Insects do not fall clearly into two groups in this respect, unless intermediates are set aside; the degree of cold hardiness varies from species to species, and must be specially determined for each one. Moreover, winters vary in many ways from year to year, while buildings and different situations within warehouses differ in the amount of protection they offer. These considerations raise many points for investigation.

In recent years, cultures of some 65 species of storage and domestic pests have been exposed to winter conditions in various unheated structures in the grounds of the Laboratory, ranging from meteorological screens to lagged cupboards in a large store-hut. Continuous temperature records have been kept by means of thermohygrographs set beside the cultures. The results have now been analysed and an account prepared for publication.

The coldest winter concerned was that of 1950-51, when a number of species were exposed from November to April or later in small jars of food material in

a meteorological screen. The list of 15 species shown to survive this exposure, in a winter colder than the average, is incomplete, since many species which would probably have survived were not included in this test. Nevertheless, it raises several points of interest. As might be expected, it includes species commonly found out-of-doors and occurring frequently in birds' nests (see Report for 1951, *pp.* 8-9), e.g. *Anthrenus verbasci*, *Dermestes lardarius*, *Tenebrio molitor*, *Ptinus tectus* and *Ptinus sexpunctatus*. It also includes the Mill moth *Ephestia kühniella*, and *Lepisma saccharina*, a silverfish generally found in warm situations, but also in birds' nests. More surprisingly, it includes *Anthrenus vorax* and *Trogoderma granarium*, two Dermestid beetles adapted to hot climates and normally found only in warmed places in Britain. Most insects tend to be more abundant in warm places because of the enhanced rate of increase. In the case of *Anthrenus vorax*, it has been suggested that the British summer temperatures in unheated sites are not high enough for the completion of its life cycle. With all the warmth-loving species, behaviour may be the major factor tending to confine them to heated sites. *Ephestia elutella* and *Laemophloeus turcicus* failed in the above-mentioned test, but survived in the same rather severe winter in a very flimsy hut.

At the opposite extreme, some species failed to survive even in an extremely mild winter (notably that of 1934-35, in earlier experiments by G. H. Mansbridge), or in a short 16-day exposure at temperatures varying about 5° down to 0°C. These included *Calandra oryzae*, *Carpophilus dimidiatus*, *Caulophilus latinasus*, *Gnathocerus cornutus*, *Laemophloeus minutus* and *L. pusilloides*, *Oryzaephilus mercator*, and *Tribolium castaneum*. Some other negative results were discounted for various reasons, and in the case of *Calandra granaria* it was established in laboratory experiments that the Insectary stock was distinctly more susceptible to cold than various stocks tested elsewhere.

Attempts to derive a summary index of the coldness of a winter as recorded on thermograph charts gave figures which fitted the biological results quite well and also proved a means of showing the protective value of the various buildings and cupboards used in the tests. (*M. E. Solomon*, *Miss B. E. Adamson*).

INVESTIGATIONS ON TYROGLYPHOID MITES

Survival and increase

The examination of the data accumulated during the past five years on th[e] life history and physical ecology of the flour mite, *Tyroglyphus farinae*, has bee[n] completed. The information has been condensed in a series of tables from whic[h] the final calculations to determine the corresponding rates of increase will b[e] made.

An investigation has been continued from last year on the life histories of th[e] mites *Tyrolichus casei* and *Tyrophagus castellanii*, for comparison with *T. farina[e]*. Reared at 15°C on wheat germ, both species developed more slowly and lai[d] considerably fewer eggs, at a slower rate, than *T. farinae*. This work will b[e] continued as time permits. It is hoped that in addition to the basic biologic[al] information provided, it will help to show what determines the relative abundanc[e] of these species under various conditions. (*A. M. Cunnington*, *Miss M. Jackson*)

Population growth on two types of wheat

Two cultures were maintained at 25°C, 75 per cent relative humidity to compa[re]

the rates of increase of *Tyroglyphus farinae* on Manitoba and on Durum wheat. The two rates were closely similar (*A. M. Cunnington*).

Resistance of eggs of the Flour Mite to low humidity

Like most Tyroglyphoid mites, *Tyroglyphus farinae* is unable to survive long exposure to dry conditions. This provides a means of control which is applicable in many circumstances, but more information is needed about the exposures necessary under various conditions. In further experiments with the eggs, which have been shown to be the stage most resistant to drying, they survived 15 days exposure at relative humidities of 20 per cent to 50 per cent at 10°C, but not exposures of 20 days or more. At 20°C, they did not survive more than 2 days at 20 per cent relative humidity, or more than 3 days at 30 per cent or 40 per cent, or more than 4 days at 50 per cent or 60 per cent. At 25°C, they did not survive more than one day at 20 per cent to 40 per cent, or more than 3 days at 50 per cent to 60 per cent relative humidity. (*A. M. Cunnington*, *Miss M. Jackson*).

Factors affecting formation of the hypopus stage

Many Tyroglyphoid mites pass at times through a highly modified *hypopus* stage, which is either an inactive form very resistant to drying or fumigation, as in *Glycyphagus*, or a form adapted for clinging to insects, as in *Tyroglyphus*. A study of the factors influencing the formation of both these types has been continued on a limited scale. This has involved attempts to find improved methods of culturing *Glycyphagus*. Officers of the Infestation Control Division of the Ministry of Agriculture and Fisheries have sent in material on which hypopi of *Tyroglyphus farinae* were found, and this has on occasions produced some hypopi in mites from laboratory cultures, but more often failed to do so. In collaboration with the Grain Storage Section, a start has been made in the experimental propagation of micro-organisms found on this material, with a view to testing their effects on hypopus-formation. (*M. E. Solomon*, *Miss R. Borrett*, *G. Ayerst*).

Fumigation with methyl bromide

In order to provide more information on the concentrations of methyl bromide necessary to control mite infestations in stored produce, a programme of work has been planned jointly by the Fumigant and Biology Sections to determine the minimum doses of methyl bromide required to kill the most resistant stages of the commoner Tyroglyphoid mites.

Eggs of *Tyroglyphus farinae* and hypopi of *Glycyphagus destructor*, which earlier work has shown to be the most resistant stages of these species, were exposed for periods of 24 hours to different concentrations of the fumigant at 10° and 15°C in 5-litre glass flasks. At both temperatures, some *T. farinae* survived when the concentration-time product was less than about 200 mg.h/litre.

The hypopi of *G. destructor* were much more resistant, and survived when the concentration-time product was 435, the highest figure yet reached in the present series of experiments. (*A. M. Cunnington*, *S. G. Heuser*).

INVESTIGATIONS ON CARPET BEETLES

Field distribution and origin of infestations

The survey of premises infested by *Anthrenus* spp., reported last year, was continued in 1953, and nearly 60 inspections have now been made. This work

has been concluded and a paper prepared for publication. (*G. E. Woodroffe, B. J. Southgate*).

Behaviour of the common carpet beetle

The study of the response of the adults of *Anthrenus verbasci* to light, (see Report for 1951, *p.* 10) has been continued. The majority of adults when placed in a dark box with an illuminated slit react positively by walking through the slit. The proportion that are positive varies with the rearing conditions and the age of the adults. Of 160 beetles collected early in the year from the inner sides of windows 90 per cent were positive. A similar result was obtained for adults collected from flowers in the summer. The proportion of positive adults varied from 7 to 28 per cent when bred at constant temperatures from 15° to 22·5°C and from 6 to 15 per cent when bred in out-buildings. Fifty per cent of those bred in a meteorological screen were positive. In general the proportion of positive adults in a group increases with age.

It has been necessary to mark beetles for a study of their paths of flight. For this purpose Process White poster colour, tinted as required with various inks etc., has been found very satisfactory. Preliminary experiments with marked beetles suggest that they fly up wind on the scent of flowers.

An actograph with a photographic recording device constructed by Mr. J. H. Hammond has been used in a study of the diurnal rhythm of activity of beetles. Normally the beetles are active during the hours of daylight. (*Mrs. G. M. Blake, Miss R. Borrett*).

Life history and physical limits

The study of the life history of *Anthrenus verbasci*, reported in previous years, has been continued.

At 22·5°C	the	mean	larval	period	was	approximately	8	months	(range	6-10·5).
At 20·0°	,,	,,	,,	,,	,,	,,	6	,,	(,,	5-9).
At 17·5°	,,	,,	,,	,,	,,	,,	7	,,	(,,	5·5-11).
At 15°	,,	,,	,,	,,	,,	,,	17	,,	(,,	11-18·5).

The effects of fluctuating temperatures on the larval period have been studied by putting out newly emerged larvae in a meteorological screen and in two small unheated outbuildings at the Laboratory. Under these conditions the life-cycle took two years, yet in each site over 50 per cent of all the individuals emerged within 2 days of the same date.

Since the primary habitat for larvae appears to be certain birds' nests (see earlier Annual Reports), it is desirable to know the temperature conditions in such nests; on the basis of this information it would be possible to estimate what proportions of the larvae are likely to take one year and two years, for their development. A dual thermocouple recorder has been acquired for a study of the temperatures prevailing in the nests.

The experiments to determine lethal heat treatments, reported last year, have also been continued. The insects were treated in closed glass vessels immersed in a water bath. At 45°C, adult beetles were killed in 42 minutes, eggs and young larvae in 45 minutes, pupae in 60 minutes, and fully grown larvae in 3 hours. (*Mrs. G. M. Blake, Miss R. Borrett*).

BIOLOGY AND BEHAVIOUR OF THE KHAPRA BEETLE

Populations in Malt Stores

Trogoderma granarium needs a high temperature for rapid breeding so that it is common only in heated buildings in Britain. Since it can thrive in very dry conditions, it has become one of the few serious pests in malt stores. On the basis of the survey commenced last year, it is possible to give the following general account of the conditions and infestations in these stores.

Malt enters storage at temperatures as high as 57°C. Temperatures around 40°C, which are most favourable for the development of *Trogoderma* are maintained for a long time against bin walls adjoining the kilns and in the middle of large bulks of malt.

New malt entering the stores is usually free of insects and becomes infested by migration of larvae from cracks in the fabric of the building and from neighbouring bins of infested malt.

In an infested bulk, the insects are most numerous against warm kiln walls and at the surface of bulks unless these positions are too hot. Within the bulk their distribution is patchy. This may frequently be caused by a number of larvae being attracted from the walls into each new kiln-load of hot malt tipped into the store. Small to moderate numbers of larvae occur near the bottom. Larvae aggregate in groups against the walls just below the malt surface and between cover sheets laid on the surface.

Larvae are continually moving from the malt to cracks in the bin walls and this migration is greatly increased when the larvae are disturbed. (The vertical movement of larvae is being investigated in the laboratory).

In emptied stores larvae occur in cracks in the walls and floor, penetrating more deeply into cool than into warm walls. When malt is piled against the walls of the kiln, heat loss from these walls is reduced so that the temperature increases very rapidly, and larvae promptly move away from them.

For the present the work at maltings has been reduced, so that some of the problems arising can be investigated in the laboratory. (*H. D. Burges*).

Laboratory study of development and behaviour

In laboratory populations of *Trogoderma granarium* at 30°C, larvae can be divided into two groups, the first group pupating in less than 50 days after hatching and the second group much later. The duration of the larval period of the latter is very variable. The proportion of larvae in this group increases in crowded breeding conditions. They have more larval moults than those which pupate early.

After the third moult, larvae with the long developmental period aggregate in cracks in which they do not feed. Cracks about 1·5 mm wide are preferred, but wider ones are occupied when enough larvae are present to fill them. These larvae may remain in the cracks for a long time and they can survive starvation better than larvae isolated in empty tubes. High temperature and sometimes fresh food induce resting larvae to leave the cracks to feed and then to pupate, although some return for a further resting period.

Larvae feeding on grain tend to eat one grain before starting another. They usually eat the germ of wheat first, then the bran, but sometimes they tunnel from the germ into the endosperm. Feeding on one grain at a time is more marked in malt, many larvae tunnelling into the endosperm until only the husk

remains. This habit greatly increases crowding and leads to a high proportion of long lived larvae. The relation of rest period to the feeding cycle is being investigated in greater detail. (*H. D. Burges*).

LIFE HISTORY AND PHYSICAL LIMITS OF THE RUST-RED FLOUR BEETLE

Tribolium castaneum is a common pest wherever cereals are stored under fairly warm conditions. In laboratory experiments it completed the life cycle at temperatures from 22·5° to 37·5°C, 10 per cent to 90 per cent relative humidity (See Fig. 1). The most favourable conditions were 37·5°C, 90 per cent relative humidity. At 40°C, development was completed at the moderate humidities of 50 and 70 per cent, but not at 90 per cent, nor at 10 or 30 per cent. All failed at 20°C. (*R. W. Howe, Miss S. M. Nightingale*).

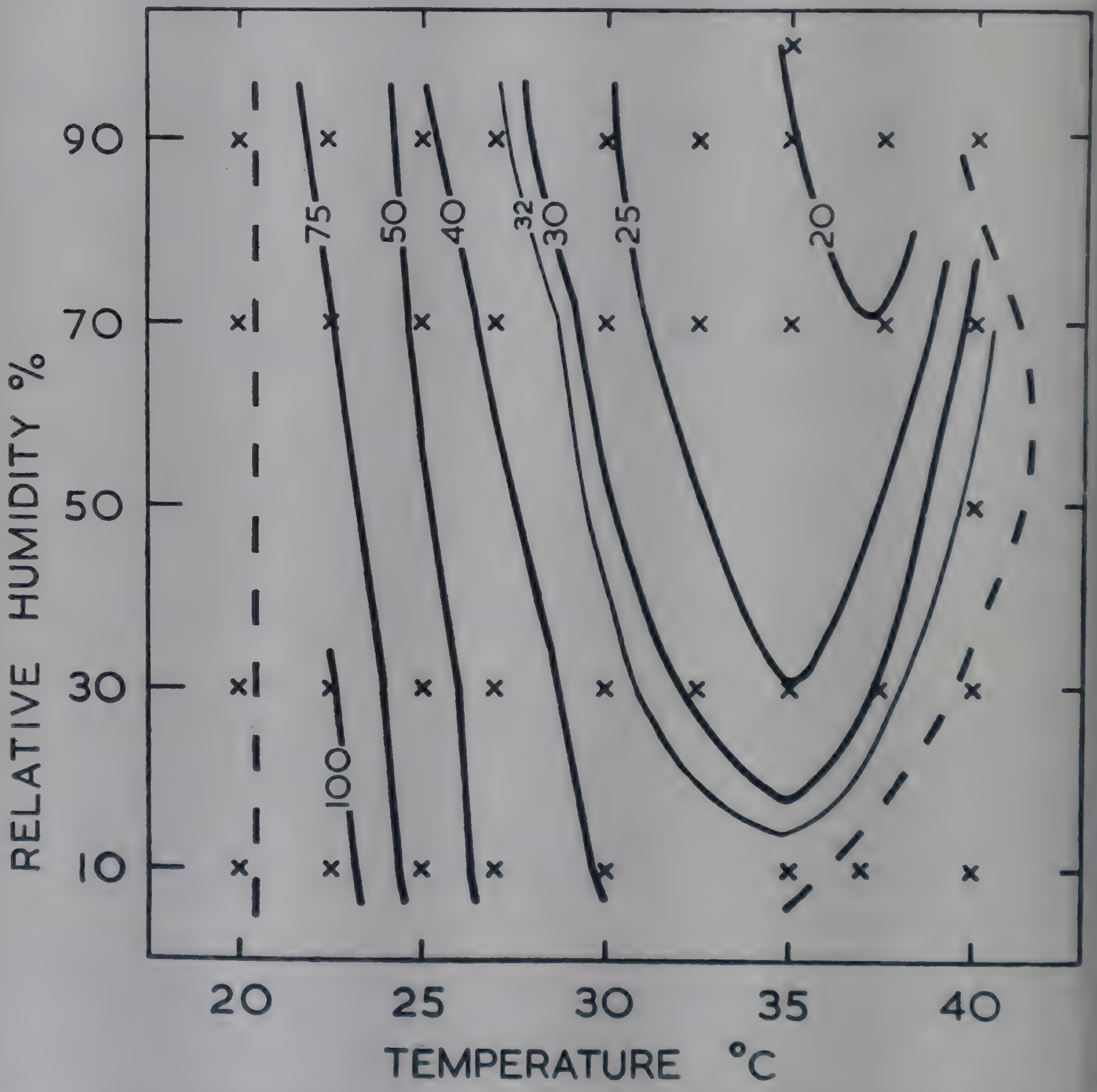


FIG. 1.—*Developmental period in days of* Tribolium castaneum *as affected by temperature and humidity; the broken lines give an indication of the physical limits beyond which development is not completed.*

LIFE HISTORY AND PHYSICAL LIMITS OF THE CIGARETTE BEETLE

Lasioderma serricorne is a widespread pest, important not only on stored

tobacco but also on cocoa and other products. In the laboratory, given a high enough humidity, it completed its life-cycle on wheatfeed at temperatures ranging from 20° to 35°C. It did best under warm moist conditions, e.g. 30°C, 80 per cent relative humidity. Under drier conditions, at 25 or 30 per cent relative humidity, the life-cycle was completed at 30°C, but at 25°C and below all the larvae died. The eggs failed to hatch at 17·5° and at 37·5°C. (*R. W. Howe, Miss J. E. Currie*).

LIFE HISTORY AND PHYSICAL LIMITS OF *Oryzaephilus* SPP

Work has continued in the laboratory on the Saw-toothed Grain beetle, *O. surinamensis*, and on the Merchant Grain beetle, *O. mercator*. Given a high enough humidity, both developed satisfactorily at temperatures from 20° to 37·5°C. They did best at 35°C, 70 per cent relative humidity. All larvae died at 40° and at 17·5°C, and none became adult at 20°C, 10 per cent relative humidity, although many *O. surinamensis* reached the pupal stage. Very few completed their development at 35°C, 10 per cent, or at 37°C, 30 per cent relative humidity. (*R. W. Howe*).

THEORY OF GRAIN HEATING

Data from earlier laboratory work in the Biology and Grain Storage Sections have been used in calculations to determine the course of events to be expected in grain heated by insects. The results agree well with observations in granaries, and show the relative importance of the factors contributing to heating. Of these factors, the most important would generally be the initial density of the insects, secondly, the initial temperature of the grain, and, thirdly, the size of the mass of grain. It is hoped that this work will assist in the difficult task of detecting hot spots in bulks of grain at an early stage of their development. (*R. W. Howe*).

TAXONOMY OF BRITISH SPECIES OF *Cryptophagus*

Throughout the year work has continued upon the taxonomy of this genus of fungus-feeding beetles, and large numbers of identifications have been carried out for the Infestation Control Division of the Ministry of Agriculture and Fisheries. A key to the British species has been prepared and is being tested. An abbreviated key including only those species likely to occur in stored products will be provided for use by the Inspectors and Area Entomologists of the Ministry. Two species have been deleted from the British list, and thirteen species added, two of which are being described for the first time. Also, several species have been consistently misidentified in the past, and these errors have now been rectified. (*G. E. Woodroffe, C. W. Coombs*).

EMBEDDING INSECTS IN PLASTIC BLOCKS

Insects embedded in blocks of polymethylmethacrylate (" Perspex ") form attractive and durable specimens, very convenient for demonstration. Previous work has shown that the standard method of preparation involving oven-curing was tedious and unreliable.

This year, attention has been focused upon the chemical aspects of the casting process, and the effect of various polymerization catalysts have been studied. As a result it has been possible to devise a reliable cold-casting technique, and a

series of excellent mounts have been prepared. An account of the new technique is being submitted for publication. (*B. P. Moore, B. J. Southgate*).

GRAIN STORAGE AND MYCOLOGY

RAPID DETERMINATION OF MOISTURE CONTENT

The report for 1952 referred to a new rapid electrical method for determination of moisture content in cereals. Development of this instrument has continued during 1953. It is not claimed that this device is accurate, indeed it is not capable of greater precision than plus or minus one per cent of moisture content which is considerably inferior to most usual methods. It is, however, very much more rapid than any other method for a determination can be made on grain in sack or bulk in about five seconds. This gives, for the first time, the possibility of testing every sack of a consignment of grain as fast as it is delivered and even comparing the top, middle, and bottom, of the same sack. It therefore seems possible that this apparatus may make up for some of its imprecision by greatly reducing the sampling errors which are usually involved in laboratory methods.

The device does not require batteries or mains, it gives an immediate and clear reading, and it can be used by unskilled persons perfectly satisfactorily. A temperature correction is necessary but it is possible to arrange for this to be effected by simple movement of the scale. The most obvious use for the apparatus is for inspection during grain buying, especially when a main reason for inspection is to detect and reject sacks of grain which are damper than some specified safety level. When used in this way a clear line marked on the dial can serve as the indicator of acceptability, which makes the reading of the instrument even simpler. (*T. A. Oxley, Miss P. M. Davey*).

RELATION BETWEEN SPECIFIC HEAT AND MOISTURE CONTENT OF GRAIN

This work has been concluded and a paper prepared for publication. The most complete series of results obtained in this investigation was for wheat (variety Bersée) for which a range of moisture content from 1·4 per cent to 33·6 per cent was covered. The relationship between specific heat and moisture content over this range was found to be not quite linear; there were three breaks in the curve but the data between the breaks could be very closely fitted by straight lines. These breaks occurred at about 1·8, 7·7, and 23·7 per cent moisture content. No difference was detectable between data obtained on desorption or adsorption curves, i.e. there is no evidence of hysteresis.

The specific heat of wheat and the apparent specific heat of water in the ranges between the breaks are given in the following table.

Moisture Content Range	*Specific Heat of Bersée Wheat*	*Apparent Specific Heat of Water*
0 to 1·8 per cent	0·307 to 0·290	− 0·10
1·8 to 7·7 ,, ,,	0·308 to 0·343	+ 0·89
7·7 to 23·7 ,, ,,	0·343 to 0·509	+ 1·23
above 23·7 ,, ,,	0·509 upwards	+ 1·07

A tentative explanation of these results is as follows. Above 23·7 per cent moisture content the apparent specific heat of water does not appear to differ significantly from unity and it is therefore assumed that the water in excess of

this percentage is neither combined nor adsorbed in any way which reduces the mobility of its molecules. Between 7·7 and 23·7 per cent the water is presumed to hydrate some substance in the wheat and the degree of hydration to change, with evolution of heat, during the cooling of the wheat from room temperature to freezing point in the ice calorimeter. Below 7·7 per cent the reduced apparent specific heat of water is presumed to be due to the powerful forces of adsorption which reduce the mobility of water molecules. The negative apparent specific heat of water below 1·8 per cent moisture content is unexplained. Too much reliance should not be placed on this since the line of closest fit is very short and the extrapolation is bound to introduce errors. Nevertheless, a very low specific heat for water at the lower limit of hydration of a material such as grain is to be expected, since the forces of adsorption must be very strong indeed.

Probably the relationship at low moisture contents would be more accurately represented by a curve which becomes horizontal or turns upwards towards the lower limit of dehydration. Its resolution into two straight lines, in the present instance, is probably fortuitous although these lines fit the data very closely.

This investigation has thus thrown useful light on the nature of water adsorption in grain as well as providing specific heat data which are valuable in calculations concerning the heating and heat exchange of stored grain. (*R. W. Disney, T. A. Oxley, G. A. Haswell*).

WHITE DEPOSIT ON BRAZIL NUTS

Study of this deposit, which causes considerable commercial embarrassment, has continued. Some more data have been obtained on shipboard by means of apparatus supplied by the Laboratory and operated by the ship's officers, and the physiology of the organism concerned (*Streptomyces* sp.) has been further studied in the Laboratory.

Convincing evidence has now been obtained to show that development of the deposit is related to air movement. Some of the nuts become whitened while they are in bulk in the climate of the Amazon, whether on shipboard or on land awaiting shipment. It has not been possible to study nuts in store on land but examination of those few which have whitened while on ship shows that their distribution is along points of air entry to the stowages. Whiteness does not develop, however, where ventilation is either very generous or very slight; there are clearly upper and lower limiting air velocities outside which the nuts do not whiten.

Striking confirmatory evidence of this has been obtained in the laboratory by exposing nuts, or inoculated agar plates, to jets of air of suitable temperature and humidity which impinge at varying velocities. A patch of whiteness develops under some of the jets but not under those of very high or very low velocity. *Streptomyces* also grows outside the point of impingement of air but not sufficiently thickly to produce an obvious whitening. It thus appears that the development of this species of *Streptomyces* is greatly stimulated by air movement within a limited range of velocities. An explanation for this unusual phenomenon is being sought.

It has hitherto been puzzling that fungi do not grow appreciably on the shells of healthy nuts in spite of favourable temperature and humidity, although *Streptomyces* does grow on them. A possible explanation is that the concentration of nutrient materials in the film of water on the shells is too low to enable fungi to establish a hold. It has now been shown in the laboratory that

Streptomyces will grow on exceedingly dilute artificial media which will only support fungi with difficulty. (*G. Ayerst, T. A. Oxley*).

ANOMALOUS GRAIN HEATING AND CARBON DIOXIDE PRODUCTION

Through the co-operation of the Infestation Control Division of the Ministry of Agriculture and Fisheries a number of samples were received of grain, apparently free from insect infestation, which was heating spontaneously, or which, although not heating in store, gave high rates of carbon dioxide production. It was found that the samples could be divided into three groups: (i) those which give a high mould count which could be presumed responsible for the heating and high " CO_2 figure " i.e., straightforward damp grain heating; (ii) those from which insects, sometimes in large numbers, bred out during a long period, i.e., where insects, not detected at the time of sampling, were the cause of the heat and carbon dioxide production; (iii) a few exceptions, mainly No. 3 Manitoba wheat from the exceptional 1951-2 Canadian harvest, whose unusual history (having lain under the snow all the winter) may have been the cause of the high " CO_2 figures " obtained.

All the results pointed to the value of the " CO_2 figure " test, which was originated by this Laboratory, in indicating whether or not grain was safe for storage, whatever the cause of the carbon dioxide production. (*Miss M. B. Hyde, G. Ayerst, D. Budd*).

HERMETIC STORAGE OF GRAIN

A brief account of the use of hermetic storage for damp grain was given in the report for 1952. It aroused considerable interest and has resulted in a number of visits to the Laboratory and requests for further information.

A laboratory scale experiment in 4-lb. domestic preserving jars with wheat of 19 per cent moisture content at 20°C was carried out. There was a progressive rise in the intergranular concentration of carbon dioxide and a fall in germination until about 26 weeks' storage, after which there was no appreciable change in carbon dioxide concentration and germination was zero. This coincided with a gradual change in the milling and baking properties (which were determined at the Cereals Research Station, St. Albans), although the grain was not regarded as damaged until after 26 weeks' storage. By 52 weeks the sour-sweet smell that developed could not be removed by airing and remained in the flour which no longer produced an acceptable loaf. It must be borne in mind, however, that the temperature of the experiment, 20°C, was considerably higher than the average likely to be encountered in practice in this country. Similar experiments on the current crop, with grain of slightly higher moisture content, are being conducted at 15°C.

The large scale experiment mentioned in the 1952 report (*p.* 16) was begun in early August, 1953, and is still in progress so that final results are not yet available.

Atle wheat was harvested by combine at an average moisture content of over 20 per cent and elevated without further cleaning into two of the three 10-ton silo bins (Plate II). These were filled almost to capacity and then sealed. Owing to the undesirability of opening the bins at intervals to remove grain samples, a representative sample of the whole bulk was sealed in fifty half-litre aluminium cans, half immediately after harvest and half after drying to a moisture content of 14 per cent. These cans were stored in conditions as near as practicable

to those anticipated within the silo bins. Some were taken at intervals and opened for examination.

After the first few weeks' storage, during which the weather was extremely hot, there was a progressive fall in the temperature at the centre of the bins, which after three and a half months' storage was more or less equal to that of the average outside temperature, although, as expected, it showed no diurnal variation.

Perhaps because of the high temperature and moisture content the carbon dioxide concentration rose more rapidly than expected and the oxygen concentration was reduced almost to zero in a few weeks. The rapid production of carbon dioxide resulted in an increase in internal pressure which was relieved by letting air out at intervals during the first few weeks. The effect of this was gradually to remove atmospheric nitrogen so that the carbon dioxide was able to reach a concentration in excess of 90 per cent within 15 days of sealing. After a concentration of 95 per cent CO_2 was reached there was no further change or increase in pressure. (*T. A. Oxley, Miss M. B. Hyde, G. Ayerst, D. Budd, Miss G. Wickenden*).

INSECTICIDES

The loss of two trained members of the group working on insecticides for use against warehouse insects has inevitably involved some loss of progress whilst new staff were undergoing initial training.

The main change in the programme of work of the Insecticide Section has been the cessation of research on the control of blowflies, although the preparation of papers for publication continues, as does the provision of advice to local authorities and industry facing problems of infestation by these insects. Part of the effort deployed on this research on blowflies has now been turned to the investigation of the reasons for the development in certain refuse tips of strains of houseflies resistant to DDT and BHC and of methods for their control: a completely satisfactory answer to the latter problem has not yet been found. The remainder, and the major part, of the effort has been devoted to a detailed investigation of the effect of application of the normally recommended measures for control of endemic infestation in warehouses by the Cacao moth, *Ephestia elutella*.

Last year it was reported that, at the request of the Colonial Liaison Officer, an investigation had been started to devise methods for the protection of beans in East Africa against severe damage by Bean weevils. The difficulties of breeding large numbers of these insects in the laboratory were overcome and sufficient progress made in the experimental work to be able to recommend a treatment using materials easily available locally. The recommendations were incorporated in a circular sent by the Colonial Liaison Officer to all Colonial territories. The work is being continued to broaden the recommendations, if possible, so that they may be applicable to more than the East African Territories.

Over 200 enquiries have been dealt with during the year mostly by letter, but in some instances of particular interest an inspection has been made and occasionally experimental treatment undertaken. To economize in time, two advisory leaflets have been prepared and duplicated to expand and replace the more or less standard letters sent in response to most requests for advice on (a) Carpet beetles and Woolly Bears (revised edition), and (b) Golden Spider

beetles. Advice has been given to several Government departments, H.M. Services, the Royal Netherlands Navy, various local government authorities, industry, and the general public.

Towards the end of the year some time has been taken up in planning new buildings to form the permanent home of the Section. Discussions are being held with the representatives of the Ministry of Works in connexion with both siting and detailed construction.

IMPREGNATION OF SACKING

The protection from infestation afforded to contained foodstuffs by jute sacks impregnated with pyrethrins and piperonyl butoxide has been further investigated in collaboration with the British Jute Trades Research Association. Two series of laboratory tests have been carried out to determine the durability of the impregnation treatment under laboratory conditions, by exposing hessian and twill sacklets to infestation by Flour beetles, *Tribolium castaneum*, and Granary weevils, *Calandra granaria*.

In the first series, the sacklets were stored in the dark either empty or filled with foodstuff (flour and/or grain); the foodstuff was either left in the sacklets continuously or changed at three-monthly intervals. This series indicated that the impregnation treatment did not start to deteriorate until about 9 months in storage, unless the sacklets contained flour changed at intervals, in which circumstances the treatment had started to deteriorate after 6 months.

In the second series, sacklets were stored empty, exposed either to diffuse daylight or to direct sunlight over a period of 7 months. At the end of the period the sacklets completely failed to exclude insects.

In addition to these tests, a larger scale experiment was carried out. In this, lots of one ton of wheat were stored in 2-cwt. twill sacks. In one part of the experiment, the sacks had been impregnated recently, and in another had been stored in darkness for seven months after impregnation. The filled sacks were exposed to infestation by Flour beetles and Granary weevils. Both types of impregnated sacks became equally but only very lightly infested, whereas control sacks (not impregnated) became heavily infested: this agreed with the results of the sacklet tests. (*E. A. Parkin*, *P. S. Hewlett*, *G. T. Bills*, *K. G. Gostick*, *C. J. Lloyd*).

MICRO-DROP APPLICATOR

An improved micro-drop applicator, working on the same principle as the previous model, has been built in the Laboratory's workshops. The method of calibration has been much improved. Individual drops of Shell Risella oil 17 (formerly called P31) delivered by the applicator are deposited on and immersed in a viscous liquid medium (based on glycerol). They are then sucked up into a special cell filled with the same medium. Their upward flotation is countered by allowing medium to flow downwards through the cell, so that the diameters of the stationary drops can be easily measured microscopically.

The new applicator is being used to investigate the action of oil-based insecticides on insects. (*P. S. Hewlett*, *Miss C. Belcher*, *M. A. Cordaroy*).

BIO-ASSAY OF PYRETHRINS

Work has continued on the method for bio-assay of the pyrethrins by loss of

weight of Flour beetles, *Tribolium castaneum*. For preparation of the pyrethrum films a simpler technique, eliminating the use of a spraying tower, is promising.

Some physiological aspects of the weight loss are being investigated. The greatest part of the loss appears to be a loss of water through the spiracles: attempts to assess other sources of loss indicate that they are relatively small. Respirometers have been set up for measurement of the oxygen uptake of beetles exposed on pyrethrum films in an attempt to discover whether the water loss is entirely an incidental effect of increased respiration. (*P. S. Hewlett, K. G. Gostick*).

RELATIVE SUSCEPTIBILITY OF INSECTS TO INSECTICIDES

An investigation has been started to determine the relative resistance to contact insecticides of a wide range of stored product insects. The object is to group the species and stages into broad categories according to their relative resistance as has already been done with 5 per cent DDT dust (Parkin, 1953). Resistance to pyrethrins, and to a mixture of pyrethrins and piperonyl butoxide, in heavy oil is now being investigated. (*P. S. Hewlett, C. J. Lloyd*).

VALONE FORMULATIONS

The general insecticidal properties of valone (2-isovaleryl 1, 3-indandione) have been examined. The compound was not highly toxic to the test insects by modern standards, but the symptoms developed suggested that the action of valone could be intensified by a suitable synergist. A limited search for this was carried out and pyrethrins and gamma-BHC were found to synergize the action of valone on Flour beetles, *Tribolium castaneum*.

The rapid lethal action of valone indicated that it might be helpful in the control of the larvae of the Khapra beetle, *Trogoderma granarium*. These larvae have previously been shown to be highly resistant to the contact insecticides at present in common use, and very slow to die after receiving a lethal dose. Valone alone was not very toxic to the larvae, but, in view of the results from the tests on Flour beetles, combinations of valone with pyrethrins or gamma-BHC were tried. Under laboratory conditions a dust containing valone and gamma-BHC proved both highly toxic and quickly lethal to the larvae. (*P. S. Hewlett, Miss C. Belcher*).

CONTROL OF BEAN WEEVILS

It was reported last year that difficulties experienced in breeding large numbers of the Bean weevils, *Acanthoscelides obtectus* and *Callosobruchus chinensis*, for insecticidal tests had been overcome. Preliminary tests were planned to answer as quickly as possible the problems of infestation by these insects in East Africa and were confined to trial of insecticidal materials locally available. From the results of these trials a recommendation was made for the admixture with each 200 lb. of beans of 6 oz. of a diatomite powder (produced in Kenya) incorporating 0·05 per cent gamma-BHC. In order to avoid any possibility of taint, the BHC used in the powder must be of the purity of lindane. This rate of admixture corresponds to 0·94 parts per million gamma-BHC on the beans, giving a reasonable safety margin in insecticidal treatment without too much dust among the product; yet it remains within the limit of 1 p.p.m. gamma-BHC acceptable to the authorities in Kenya and to the importers and processors in the U.K.

Other bases for the powder and the value of DDT as the insecticide are now being investigated, because diatomite has valuable intrinsic insecticidal properties against Bean weevils and is not available in other colonies, and because gamma-BHC is thought not to be sufficiently persistent under tropical conditions. (*E. A. Parkin, G. T. Bills*).

PROTECTIVE EFFECT OF COW-DUNG ASH

A small series of tests was undertaken for the Colonial Liaison Officer to determine whether cow-dung ash, as mixed with grain in Bechuanaland, conferred any protection against Granary weevils. At concentrations up to 4 per cent in wheat, the ash gave no detectable protection against infestation and showed no evidence of insecticidal effect. Any protection obtained in practice must therefore be ascribed to the purely mechanical protection afforded by admixture of relatively very large quantities of the powder. (*E. A. Parkin, G. T. Bills*).

PYRETHRUM POWDER FOR CONTROL OF THE CACAO MOTH ON GRAIN

Another attempt (see Ann. Rept. 1950, *p.* 18) has been made to carry out a practical trial of surface treatment of bulk floor-stored wheat to secure protection against the Cacao moth, *Ephestia elutella*. On this occasion about 400 tons of No. 3 Manitoba wheat were treated on the surface with a powder containing 0·2 per cent pyrethrins and 2·0 per cent piperonyl butoxide at the rate of 2·0 lb. per 100 sq. ft. There was a moderately heavy endemic infestation of the moths in the stowage. Unfortunately, as has happened during previous attempts to do long-term experiments of this sort on large quantities of grain, delivery of the grain began before the final observations could be made. Nevertheless, the indications were that the treatment as applied was not sufficiently successful to warrant recommendation for practical use. (*E. A. Parkin, G. T. Bills*).

CONTROL OF THE CACAO MOTH IN WAREHOUSES BY SPRAYS

At the request of Infestation Control Division, Ministry of Agriculture and Fisheries (M.A.F.), an investigation has been started on spraying methods for control of the Cacao moth, infestations by which appear to have become increasingly frequent during the last few years. Full-scale treatments were applied by the P.I.L. team to various stowages in a large London warehouse storing mixed, bagged commodities including cocoa, coffee, and spices.

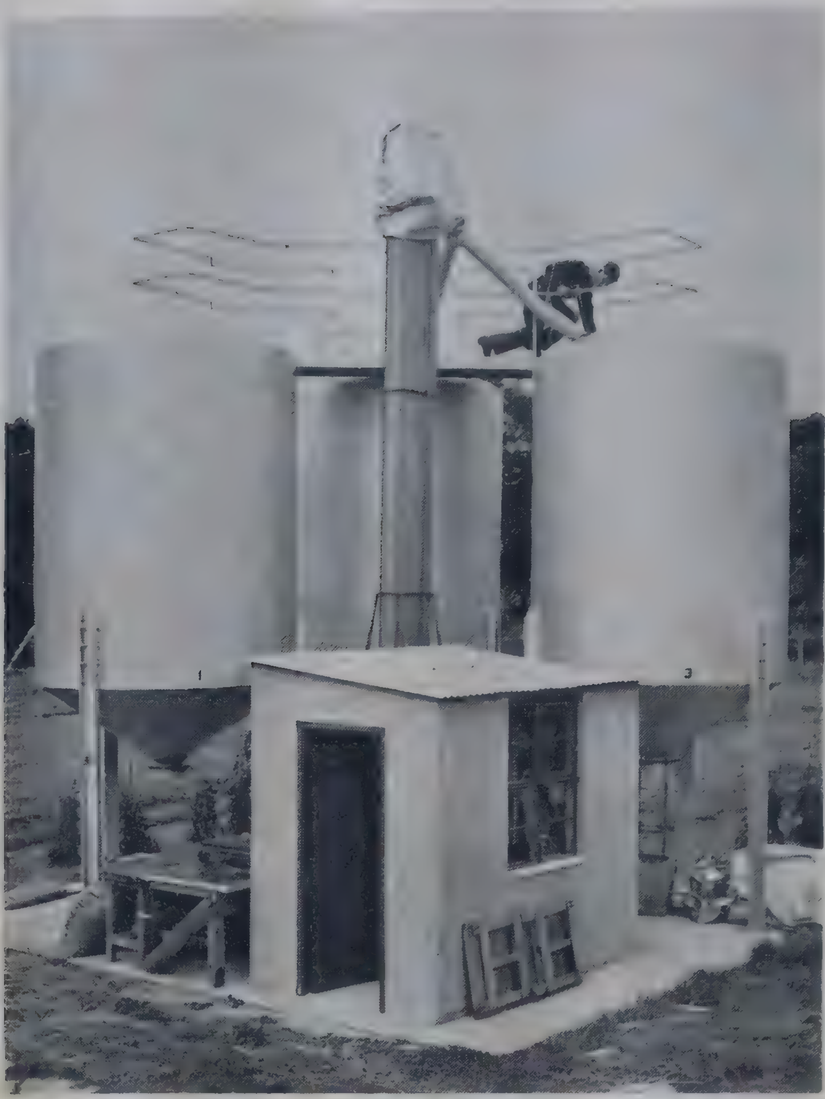
On one floor the standard M.A.F. recommendations were followed, the internal structure of the building being treated with DDT dispersible powder and the commodities sprayed every 3 to 4 weeks with a mixture of 0·3 pyrethrins and 3 per cent piperonyl butoxide in heavy oil. On a second floor the structure was not treated but the commodities were sprayed weekly with the pyrethrum/piperonyl butoxide mixture by means of a portable electric machine producing a heavy fog which was directed at the stowed goods from a distance of 3 to 10 feet (Plate IV(*a*)). A third floor was left untreated.

Weekly estimations were made of the numbers of live moths in the centre stowage of each floor during the emergence period which extended from early June to early August. The numbers of moths, although relatively small, indicated that the treatments were killing a high proportion: at the peak period of emergence there were 3,530 moths in the control stowage, 490 in the sprayed stowage and 270 where the fogging machine was used. Those found in the

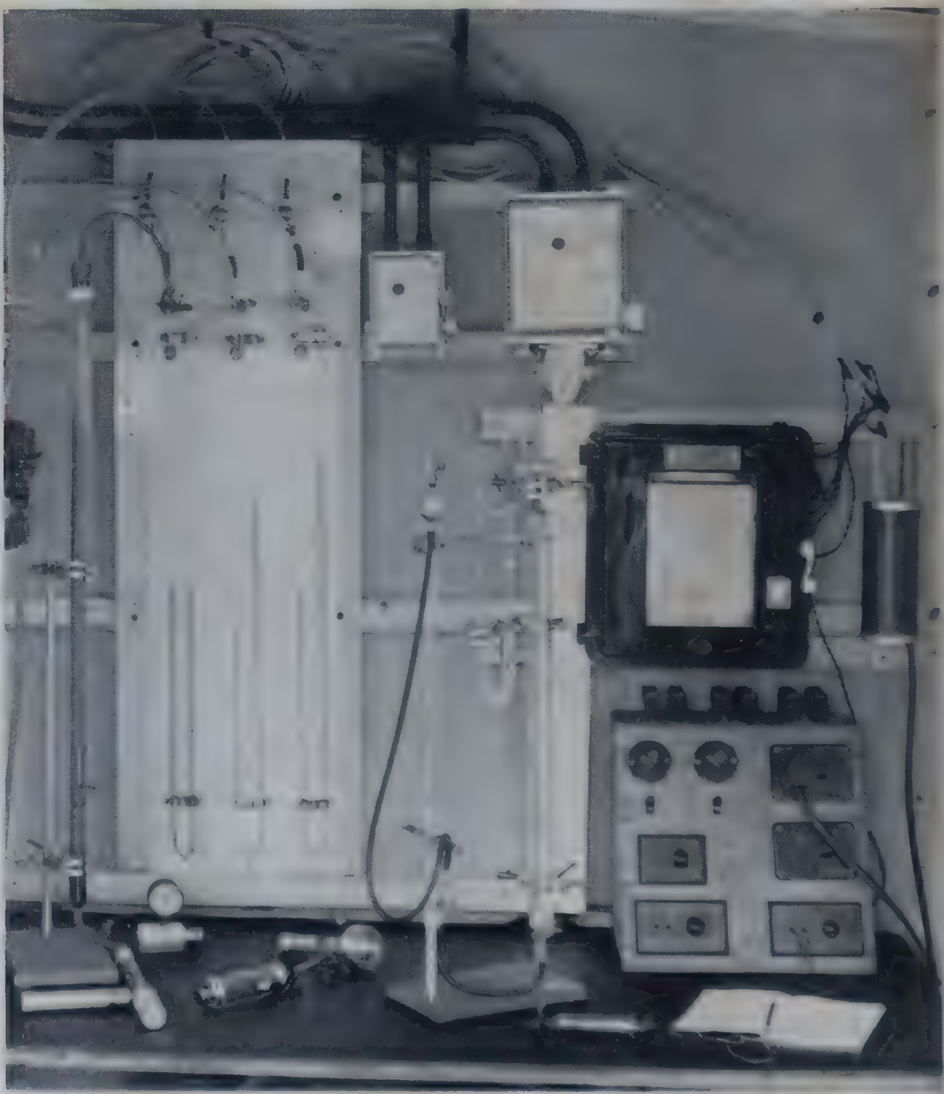
(A) *Opening of Biochemistry Building by Sir Ben Lockspeiser*

(B) *The Radiochemistry laboratory in the new Biochemistry Building*

PLATE I



(*a*) The experimental 10-ton silos and instrument shed



(*b*) Interior of instrument shed, showing manometers, temperature recorder and gas analysis apparatus

Air tight storage of grain

PLATE II

(A) *Tests of permeability to water vapour of different materials for use as "dunnage" for stored grain*

(B) *Spraying rubbish tip for control of DDT resistant houseflies*

PLATE III

(*a*) Application of insecticide as a fog

(*b*) Bags of infested cocoa waste under observation at the Laboratory

Control of Cacao Moth in a warehouse

PLATE IV

treated stowages may well have been newly emerged moths which would be killed before they could lay eggs.

To measure the degree of control of consequent larval infestations, four bags of cocoa waste were stored on each of the three floors during the entire experimental period. They were then transported to the Laboratory and all the larvae migrating from them were trapped and counted (Plate IV(*b*)). Counts are almost completed and, to date, 6,082 larvae have migrated from the sacks on the untreated floor, 14 from those in the sprayed stowage, and 11 from those where the fogging machine was used.

The conclusions which can be drawn from this season's work are (a) that the treatment recommended by M.A.F. is adequate for the protection of bagged goods, if properly carried out; (b) that a machine producing a dense mist can give equally good protection if suitably used, and (c) that a few bags of infestable material left in a relatively lightly infested stowage can provide the nucleus of a heavy infestation in the following year.

The investigation will continue with a view to developing more economic and less laborious methods of control. (*A. A. Green, A. M. Simmonds, Miss M. J. Kane*).

CHEMICAL INVESTIGATIONS OF CONTACT INSECTICIDES

The search for an alternative chemical basis for pyrethrum assay has continued, with emphasis upon the ketonic properties of the active constituents. These active constituents are exceptionally difficult to isolate in a pure condition, and it has therefore been necessary to adopt the related synthetic compound, allethrin (which may be obtained in pure, crystalline form), as a standard for preliminary tests.

Various hydrazine derivatives have been selected for trial as quantitative reagents, and of these, 2 : 4-dinitrophenylhydrazine has proved the most satisfactory. Using this material, it has been possible to estimate the allethrin content of commercial samples, either by gravimetric or spectrophotometric means, but further trials are necessary before the value of the method can be fully established.

When applied to a purified pyrethrin concentrate, this method gave a value for total pyrethrins some 15 per cent lower than that obtained by the mercury reduction method, the discrepancy being largely associated with the pyrethrin II fraction. It is not yet clear whether this discrepancy is due to some shortcoming of the new method, or whether the lower value represents a closer approach to the true content of the concentrate. (*B. P. Moore*).

MOTHPROOFING TESTS

The Laboratory has continued to participate in collaborative tests arranged by the Mothproofing Committee of the International Wool Trades Organization. The results obtained by the method of assessing mothproofing efficiency mentioned in the Report for 1952, *p*. 23, were statistically analyzed and discussed at meetings in Paris (January) and Brussels (May), attended by Dr. E. A. Parkin. Although when weight losses from " test " samples were related to the weight losses from a short series of " standard " samples some reduction was evident in the variability of the results, the variation between laboratories remained excessive for the purposes of the test. It has therefore been agreed to undertake

another trial in which much closer attention will be paid to control and measurement of factors which have so far been the responsibility of each laboratory e.g. breeding and exposure temperature and relative humidity, culture medium. The organization of this test has taken a considerable time but everything is now ready for a start to be made. Repetitive testing will be done at intervals during 1954 to gain information also on the variability of results obtained by each participating laboratory over a period of time. It is anticipated that the amount of variation found in this major test will have to be accepted as the minimum attainable with this type of technique.

Several ancillary experiments have been done in connection with this search for a reliable technique for determining mothproofing efficiency. For example, the provision of an 8 mm free space round the edge of the sample in the container did not significantly influence the weight loss from the sample, although the larvae were no longer continuously confined on it. In addition, the weight loss from samples not given any proofing treatment has been shown to be greater when they were handled with unwashed hands than when handled with clean rubber gloves and forceps: the difference was negligible when impregnated samples were used. (*E. A. Parkin*, *Mrs. P. J. Maycock*, *Miss D. G. Blackman*).

CONTROL OF CLOTHES MOTHS

As opportunity has afforded, tests have been made to assess the value of a number of materials which have become commonly accepted as protectants against Clothes moth attack in the home. Lack of accommodation has prevented the setting aside for this work of a room in which a free and heavy infestation of moths could be worked up. Exposure of samples to the insects has therefore had to be made in relatively small glass vessels in which high vapour concentrations of any volatile materials build up. If a vapour is toxic, the moths will soon be affected and killed by the abnormally high concentration or, if a vapour is non-toxic, any repellent effect it may have may be masked by the lack of a normal concentration gradient. It is thus very difficult to interpret the results of such small-scale laboratory tests in terms of ordinary practice.

A small amount of each substance under test and a piece of serge cloth were wrapped in brown paper and exposed to attack by adult Common Clothes moths, *Tineola bisselliella*, in a 7 lb. glass jar closed with a muslin top. The concentration of vapour built up in the jars by paradichlorbenzene or naphthalene crystals was sufficiently toxic to kill the moths quickly and prevent infestation of the cloth, but such concentrations would not often occur in practice. No protection, however, was afforded to cloth wrapped with lavender seeds, pepper, Epsom salts, or small pieces of new strap leather, all of which have been recommended as protectants against moth attack. It must be stressed again that the results with the paradichlorbenzene and naphthalene are optimistic when considered in terms of normal practice in the home, whereas the results with the remaining substances listed are possibly somewhat pessimistic. However, it is clear that no reliable degree of protection can be expected from the latter group. (*Mrs. P. J. Maycock*, *Miss D. G. Blackman*).

An interesting outbreak of the Large Pale Clothes moth, *Tinaea pallescentella*, was inspected in a wool warehouse and its origin traced to a part of the ground floor of the building in which damaged drums of powdered casein had been stored. The insects were breeding extensively in casein spillage under the

oorboards. Control was effected by cleaning out the casein residues, and praying to kill the free-flying moths. (*E. A. Parkin, A. A. Green*).

ONTROL OF CARPET BEETLES

A number of insecticides have been tested against Woolly Bears, i.e. larvae of he Carpet beetles, *Anthrenus verbasci* and *A. vorax*. Larvae of both species vere exposed on various substrates to a series of concentrations of insecticidal owders, sprays, and deposits from oil sprays and smokes. The larvae of 1. *vorax* were considerably more susceptible to the insecticidal treatments than hose of *A. verbasci*. It is the latter species that is common in this country and, lthough many of the insecticides and methods of application tried were successful n ultimately killing the insects, death took place so slowly—usually several weeks vere needed to attain 100 per cent kill of a group of larvae—that the treatment vould not appear very satisfactory in practice. The findings of this work have een incorporated in a general form in a revised edition of the Laboratory's dvisory leaflet on these insects. (*Mrs. P. J. Maycock, Miss D. G. Blackman*).

A request for help in assessing the value of two methods of BHC treatment of ervice uniforms has involved much experimental work from which it appears hat neither method can be relied on to give 100 per cent kill but both can exert very considerable and useful degree of control, so long as the garments are ung during treatment so as to be only loosely touching. (*E. A. Parkin, Ars. P. J. Maycock, Miss D. G. Blackman*).

ONTROL OF BLOWFLIES IN REFUSE

The Islington Borough Council has continued to implement the Laboratory's ecommendations for control of blowflies at the railway sidings. Reports from ouncil officials and our own observations indicate that the high level of control btained experimentally is being maintained in ordinary practice. (*A. A. Green*).

DT-RESISTANT HOUSEFLIES

The flies collected last year from a refuse tip have maintained their resistance DDT while breeding under laboratory conditions for 24 generations. It has een shown that, although highly resistant to both DDT and BHC, they are illed by normal doses of pyrethrins.

The flies continued to breed at the tip during 1953 and opportunity was taken or the practical trial (Plate III(B)) of some insecticides containing pyrethrins but o chlorinated hydrocarbon compounds. A pyrethrum emulsion was effective gainst those flies wetted during the spraying operation but the residual deposit st toxicity so quickly as to be ineffective. Dusts were much more effective and mixture containing 0·1 per cent pyrethrins and 1·6 per cent piperonyl butoxide, pplied as a daily light dusting, quickly reduced the population to less than 10 er cent of its original size. Despite regular and frequent treatment of the tip, small nucleus of resistant flies remained throughout the summer.

The presence of similarly resistant flies has been confirmed at two other tips the Greater London area. (*A. A. Green, A. M. Simmonds, Miss M. J. Kane, . S. Tyler*).

HE OVERWINTERING OF HOUSEFLIES

A study was made of a heavy infestation of houseflies which survived the inter of 1952-3 by breeding continuously at a tip for domestic refuse. The

adult flies flew only short distances and confined their activity to the warm air within a few inches of the surface of the fermenting tip. Ovipositing flies were able to crawl amongst the loosely packed refuse to a position below the surface where temperatures of 25° to 30°C favoured the successful development of larvae. (*A. A. Green, A. M. Simmonds, P. S. Tyler*).

THE CONTROL OF PHARAOH'S ANT IN HOSPITALS

Continued experiments have shown that even heavy infestations by Pharaoh's ant, *Monomorium pharaonis*, in hospitals can be controlled by systematic application of chlordane. In each of five infested hospitals visited and in all other cases reported to us the seat of infestation was in the underground ducting carrying the steam and hot water pipes. It has been found, however, that treatments should always begin at the periphery of an infestation and work towards the centre, because ants tend to move away from the treated areas and establish sub-colonies in previously uninfested places.

Treatment above ground consisted of applying bands of 2 per cent chlordane in refined kerosene to the foot of all walls and around all pipes leading from the ducts; this mixture dried quickly and the residual film was neither visible nor sticky. Below ground a higher concentration of chlordane (5 per cent) could safely be used but a non-inflammable oil carrier was substituted so as to avoid the risk of building up a dangerous concentration of oil vapour in the hot, enclosed ducts.

Recent experiments at a hospital where the ducts are small and inaccessible, have shown that control can be achieved by using a portable electrical machine to blow a heavy mist of insecticide along the ducts. The machine was inserted into the ducts at 30-feet intervals and 2 pints of 5 per cent chlordane used for each 30 feet of 3 × 3 ft. ducting. Complete control was achieved in all but a few narrow side-tunnels which needed to be treated separately. (*A. A. Green, Miss M. J. Kane, P. S. Tyler, D. G. H. Halstead*).

CONTROL OF COCKROACHES

A method has been developed for breeding large numbers of the German cockroach, *Blattella germanica*, under laboratory conditions and without the usual risk of insects escaping. The nymphs from a single egg capsule are cultured in a cell so that insects of known age and origin are available for comparative tests of insecticides.

A field experiment has been conducted in an old hotel which was heavily infested with the Oriental cockroach, *Blatta orientalis*, and which adjoined similar old and infested buildings. Smoke generators were used in the kitchen at the doses recommended by the manufacturers. Lindane was not very effective and killed only about 20 per cent of the population. DDT was much more effective and achieved almost complete control of the remaining insects. After clearing the building of resident cockroaches, there remained a nightly migration along the space between floor and ceiling which was common to the hotel and the adjoining buildings. This was overcome by the application of 10 per cent DDT dust barriers beneath the floor boards. (*A. A. Green, A. M. Simmonds, P. S. Tyler*).

VARIATION IN INSECT RESISTANCE

In continuation of the series of monthly standard tests to determine the

variability in resistance of a special stock of the Flour Beetle, *Tribolium confusum*, controlled exposures of batches of beetles have been made regularly throughout the year. Comparison of the results of the 1953 series with the more fully analyzed results obtained in 1952 indicates that (a) the experimental data have fitted regression lines, representing probit kill plotted against log exposure time, as well in 1953 as in 1952; (b) the mean level of resistance has been practically identical in both years but the contributory data of 1953 not quite within the limits of statistical homogeneity; (c) the slopes of the regression lines have formed a homogeneous series. When the data for male and female beetles are considered separately, it appears that although the females were again rather more variable than the males, there was in 1953, unlike 1952, no significant difference in the level of resistance of the two sexes. Several minor experiments were also carried out on the special stock during the course of the year.

A considerable time has been given to trying to increase further the resistance of the stock most resistant to methyl formate last year. Eight generations have now been treated and the maximum resistance so far obtained is about 1·7 times that of the standard stock. Selection will be continued for a few more generations before it is concluded that a really resistant strain is not likely to appear.

A small stock of " dark " beetles has been built up from an abnormally dark female which appeared as a mutant in the special stock of *T. confusum*. The resistance of this line to methyl formate fumigation is about 0·86 times that of the special. (*J. A. Hope*, *K. G. Gostick*, *Miss R. Phillips*).

FUMIGANTS

The most important item of field work during the year has been the further series of tests carried out in a pair of silo bins fitted for circulation of air and fumigant. The additional data which these have produced have been of assistance in answering enquiries. A number of these have related to new grain silos which are being planned or are under construction in certain African territories and in which fumigation in bins fitted for circulation has formed an integral part of the scheme.

Progress on some other investigations has been limited by the difficulties of analysing gas samples containing mixtures of certain halogenated hydrocarbons. A considerable amount of preparatory work has been carried out in the laboratory on sampling methods which would allow the use of the infra-red spectrophotometer for the analysis of these mixtures.

The programme of work on vacuum fumigation methods has not included any further tests on penetration of methyl bromide into commodities but the Laboratory has been in close touch with work in progress in the Department of Agriculture in Canada.

Preliminary reports have been received from the Science Service Laboratory, London, Ontario on tests carried out on a larger scale than is possible in the fumigation chambers at Slough. Here the study of the sorption of fumigants at reduced pressures has been continued and a start has been made on the study of the effect on the resistance of insects of the various conditions which can occur during the different techniques of vacuum fumigation.

A more detailed study of the sorption of fumigants by different kinds of grain has been related to tests on the resistance to fumigants of the pre-adult stages of

Calandra granaria reared on the same kinds of grain. The first fumigant to be tested in this way is carbon tetrachloride because this is one to which these pre-adult stages show a high resistance which must be taken into consideration when calculating the dosage to be used in practice. A technique for carrying out these toxicity tests has been worked out and tested and preparations made for carrying out the main series of tests next year.

A considerable amount of time has been spent on the preparation of an advisory pamphlet on the method of fumigation with methyl bromide under gas-proof sheets which will be published shortly.

FUMIGATION IN SILO BINS FITTED FOR GAS CIRCULATION

In the Report for 1948, *p.* 18, a description was given of tests carried out with a gas circulating system fitted to a steel silo bin in Liverpool. Early this year the Company owning this plant decided to prepare it for regular use. This was to be done by piping an adjacent bin of the same type and fitting the necessary valves so that either bin could be connected to the " blower " unit. The Laboratory was invited to assist in bringing this plant into condition for use. A number of small leaks were located and eliminated during the early tests but it proved difficult to overcome completely leakage at the slide on the grain outlet from each bin. In this particular plant a small reduction in pressure was produced in the bin by the end of the period of circulation and the leakage at the slide (in the absence of all other leaks) appeared to be the cause of low concentrations measured near the bin bottom in the period immediately following the end of circulation. This was overcome by opening a valve at the top of the bin at the end of the period of circulation so that the whole bin was brought to atmospheric pressure.

During the tests a good deal of useful information concerning pressures and air flows in the system was obtained. In addition, gas sampling results have made possible the preparation of a tentative schedule of dosages of methyl bromide for the fumigation of several different types of grain in this system. (*W. Burns Brown*, *H. K. Heseltine*, *J. D. Pearson*).

FUMIGATION OF LARGE BULKS OF GRAIN ON FLOORS

During the year several fumigations of large bulks of grain in sheds have been ordered by the Infestation Control Division of the Ministry of Agriculture and Fisheries. These have been similar to those mentioned in the Report for 195[illegible] (p. 30), but the fumigant used has been a 1 : 1 mixture of ethylene dichloride and carbon tetrachloride with the addition of 5 per cent by volume of ethylene dibromide.

In the absence of suitable methods for the analysis of concentrations of such a fumigant mixture in air the amount of work which the Laboratory could carry out in checking the efficiency of this method of fumigation has been limited. At one fumigation, however, gas concentrations of ethylene dibromide only were measured and it was shown that it is possible to obtain effective concentration time products for this component in the surface layer of grain (for example, to a depth of 2 feet).

At this and other fumigations a certain amount of checking by biological means has been carried out by the Laboratory. Cages of test insects have been used and samples of infested grain examined. The results confirm that this

method of fumigation is giving a useful measure of control. More detailed investigation must, however, await the introduction of a satisfactory method for the analysis of gas samples of fumigant mixtures of this type. (*H. K. Heseltine, J. D. Pearson, Miss B. D. Hole*).

THE EFFECT OF FUMIGATION WITH METHYL BROMIDE UPON THE MALTING AND BREWING QUALITY OF BARLEY

Although large quantities of barley intended for animal feeding stuffs have been fumigated with methyl bromide in this country it has been considered unwise to use this fumigant in the treatment of barley for malting before tests had been carried out to determine whether its malting and brewing quality would be affected. Some tests have now been carried out jointly by the Pest Infestation Laboratory and the Brewing Industry Research Foundation. Two varieties of barley, Spratt Archer and Kenia, were tested at two moisture contents, approximately 12 and 16 per cent, and two levels of dosage, giving concentration-time products of 250 and 415 mg h/litre respectively. After a period for airing, malting of the samples was arranged by the Brewing Industry Research Foundation where germination tests, analyses of the malts and brewing tests were carried out. The germination of all the treated samples was affected, those with the higher moisture content and treated at the larger dose, showing the most damage. The malts prepared from the barleys treated at the higher level gave less extract than the control samples. Satisfactory beers were brewed from all samples. In tasting tests adverse comments were made against one of the beers from barleys treated at the high level, but the tests were not on a sufficient scale to allow a definite conclusion that the effect was due to the fumigation. It would appear that fumigation of malting barley with methyl bromide cannot be recommended unreservedly. A joint report of these tests is being prepared for publication.

EFFECT OF TOTAL PRESSURE ON SORPTION OF FUMIGANTS

Continuing work started in 1952, the rate of sorption of methyl bromide by wheatfeed and by whole wheat has been determined at 5 cm Hg and at atmospheric pressure. Results indicate that variation in total pressure has no significant effect on the rate of sorption by wheatfeed. The experimental measurements of sorption of methyl bromide by whole wheat, which were carried out on a 10 kg sample in a chamber of 170 litres capacity, showed that in a short exposure at reduced pressure the fall of free space concentration was appreciably greater than in a treatment at atmospheric pressure over the same period. This was due to the higher initial rate of sorption at the reduced pressure. After this initial period the rate of sorption tended towards that found at atmospheric pressure.

Since the rate of sorption of methyl bromide by the finely divided wheatfeed was shown to be unaffected by total pressure the higher initial rate of sorption by whole wheat at 5 cm Hg must be due to the more rapid penetration of the gas into individual grains at this pressure. (*S. G. Heuser, R. B. Hedley*).

SORPTION OF FUMIGANTS BY DIFFERENT GRAINS

A systematic investigation of the relative amounts of fumigants sorbed by different cereal grains under standard conditions has been commenced. These data must be obtained to enable fumigant dosages in practice to be estimated or

modified to take into account sorption losses which may vary according to the nature of the commodity. The programme of work includes the measurement of sorption of carbon tetrachloride, ethylene dichloride and methyl bromide vapours by wheat, barley, maize, oats, sorghum and rice. The grains are conditioned to the same temperature and relative humidity before exposure to the fumigant. Each test is carried out at three levels of dosage covering gas concentrations normally used in the field. Results with carbon tetrachloride show that wheat sorbs about twice as much vapour as barley under comparable conditions while sorption by yellow maize is nearly twice as much as that by wheat. (*S. G. Heuser, Miss C. E. Thomas*).

RESIDUES IN WHEAT FUMIGATED WITH ETHYLENE DIBROMIDE

Following trials of the surface application to bulk grain of fumigant mixtures containing ethylene dibromide, and the demonstration of its high toxicity to insects an investigation is being made into the nature and size of the residues which may be left in fumigated wheat. The sorption of ethylene dibromide by whole wheat and ground wheat is also being studied together with experimental determinations of the rate of airing of fumigant from the grain. Tests with ground wheat indicate that physical sorption of ethylene dibromide is very large. It has however been shown that after exposure of ground wheat to a much higher concentration of fumigant than would normally be met in practice (c. 1600 mg h/litre) almost all the fumigant could be recovered unchanged after prolonged airing at room temperature and residual bromide was only about 20 p.p.m. A method has been developed for the determination of unreacted ethylene dibromide associated with wheat after fumigation. (*S. G. Heuser, Miss C. E. Thomas*).

FUMIGATION OF SUGAR WITH METHYL BROMIDE

Residual bromide determinations were made on a number of samples from bags of sugar of various grades which had been fumigated with methyl bromide in a test arranged by the Infestation Division of the Ministry of Agriculture and Fisheries. Dosage was at the rate of 16 oz. per 1,000 cu. ft. and the time of exposure 24 hours. The bags were aired for 48 hours before samples were taken for analysis of residues. No residual bromide was detected in any sample. (*S. G. Heuser, Miss C. E. Thomas*).

TOXICITY OF FUMIGANTS TO INSECTS

So far the effects of physical conditions have been investigated one by one by means of simple comparative tests. These tests have been of an essentially exploratory nature and some account of them has been given in earlier annual reports. Last year attention was drawn to the difficulty which is found in estimating how nearly laboratory data will apply to practical conditions. This difficulty arises largely because the tests have shown that mortality depends on conditions before and after as well as during fumigation and that the rate of mortality no less than the final mortality can be affected, these effects differing according to the kind of insect and the fumigant. For this reason preliminary estimates of toxicity have been made from tests, such as those described in the Report for 1951, *p.* 23, which were capable of measuring only large differences. This year particular attention has been paid to the question of how to increase the precision of these estimates. The tests made so far have been reviewed and

it is considered that sufficient general information about how physical conditions can affect mortality has already been obtained. It is also considered that the simple comparative tests which served to indicate the existence of these factors are inadequate to measure their practical importance. This can only be done by factorially arranged tests in which all the relevant factors are tested simultaneously. This principle has been applied on a limited scale in some further tests with methyl bromide and also in the tests on the toxicity of this fumigant under reduced pressures which are described below. It is also planned to continue the preliminary type of test on additional species. No such toxicity tests have been made this year but some time has been spent on determining suitable culturing methods for species which include *Laemophloeus ferrugineus*, *Callosobruchus chinensis*, *Gnathocerus cornutus*, *Dermestes lardarius* and *Ephestia elutella*. (*Miss E. M. Reynolds*).

THE TOXICITY OF METHYL BROMIDE UNDER REDUCED PRESSURES

A series of tests has been started on the toxicity of methyl bromide under reduced pressures. The object of the work is to find out the extent to which the concentration-time products required for a complete kill in fumigations at reduced pressure differ from those required at atmospheric pressure. In addition to temperature and humidity, the conditions during fumigations at reduced pressure may differ, according to the fumigation method, in both the level of reduced pressure and in the length of time for which the reduced pressure is maintained. Each of these factors has been tested at two levels in a series of sixteen four-hour fumigations in which every combination of these conditions was tested once. The levels chosen were:

temperature, °C	25	15
relative humidity, per cent	70	45
absolute pressure, cm Hg	15	7
duration of reduced pressure, h	4	1

The gas concentration was the same in all tests. Eight kinds of test insect were used. These were *Tribolium confusum* adults and pupae, *Ptinus tectus* adults and cocoons, *Laemophloeus minutus* cocoons and *Calandra granaria* adults, older and younger pre-adult stages. To make the results of more direct practical value large samples were used so that some survival would be expected with concentration-time products sufficient for 99·5 per cent kill.

The results so far obtained have been compared with those obtained earlier at atmospheric pressure at 25° and 15°C and 70 per cent R.H. In most cases the insects were more susceptible at reduced pressure than at atmospheric pressure. It is estimated that the greatest increase in susceptibility amounts to a reduction of the c.t. product required for a 99·9 per cent kill at atmospheric pressure to between a half and a third. An increased susceptibility of this order was found with all the insects under one or other of the test conditions but with all of them the increase was substantially less than this in some of the tests.

Toxicity was always greater at 25°C than at 15°C. Humidity was only sometimes important and then toxicity was almost always greater at 70 per cent than at 45 per cent. The different kinds of insects showed great diversity in the effect of the time of reduced pressure. In spite of these differences there was, with very few exceptions, agreement in the fact that in the four tests in which the

reduced pressure was maintained for 4 hours mortality was higher at 15 cm than at 7 cm pressure whereas in the tests in which the reduced pressure was maintained for only one hour mortality was higher at 7 cm than at 15 cm pressure. With 4 hours of reduced pressure the mortality achieved by a given c.t. product must therefore in many cases reach a maximum at some pressure between 7 cm and atmospheric whilst with only 1 hour of reduced pressure the maximum is reached at a pressure below 15 cm. (*W. Burns Brown, Miss E. M. Reynolds, Miss M. F. East, Miss C. E. Thomas*).

The control of all the conditions during this series of tests called for considerable care and a number of trial runs were made to test whether sufficient control could be obtained. Accurate dosing was assured by obtaining the correct weight of methyl bromide in a small closed vessel from which it could be vaporized into the chamber. As in all our toxicity tests the concentrations obtained in the chamber were checked by withdrawal and analysis of gas-samples. No special measures were made to control the small variations of temperature which occurred when the pressure was lowered or raised since similar changes occur during practical fumigations. In these tests on an almost empty chamber large changes in relative humidity can occur when the pressure is lowered or raised. In practical fumigations the relative humidity tends to remain in equilibrium with the moisture content of the load and therefore in this series of tests an attempt was made to maintain the relative humidity at a constant level throughout each treatment. After each reduction in pressure water was introduced by distillation, and partially dried air was used to restore the pressure to atmospheric. In addition, trays of aqueous glycerol solutions were used in the chamber to assist in maintaining constant conditions. A thermohygrograph placed in the chamber provided a record for each test. (*S. G. Heuser, R. B. Hedley, Miss C. E. Thomas*).

THE USE OF PRE-ADULT STAGES OF *Calandra* SPP. AS TEST INSECTS

By fumigating samples of grain which are infested with pre-adult stages of *Calandra* spp. and counting the number of survivors which emerge as adults it has been found that these stages of *C. granaria* in particular, are highly resistant to most of the fumigants which have been tested. They are, therefore of considerable importance as test insects in both laboratory tests and field trials. A number of tests have been made during the year on various points in connection with improving the sensitivity of the experimental method. Sampling errors have been reduced and data on natural mortality at 10° and 15°C obtained from which an appropriate increase in the size of samples fumigated at these temperatures and retained there for different periods can be ascertained. Culturing methods to give a better segregation of the pre-adult stages in separate cultures are being checked by dissection of samples. Tests are in progress on the rate of carbon dioxide production after fumigation to show how soon after treatment a complete kill can be detected by this method. (*Miss E. M. Reynolds, S. G. Heuser, Mrs. B. M. Reynolds, Miss M. E. East, Miss C. E. Thomas*).

From time to time, as opportunities arise, the resistance of insects from the field has been compared with that of the laboratory stocks. Several hundred adult *Calandra granaria* were obtained from an infestation of barley in a warehouse. They were used to set up cultures of pre-adult stages in Manitoba wheat at 25°C. The resistance of these pre-adult stages to ethylene dichloride and to ethylene dibromide at 25°C was compared with that of the laboratory stock.

No large differences were found. (*Miss E. M. Reynolds, S. G. Heuser, Miss M. F. East, Miss C. E. Thomas*).

The pre-adult stages of *C. granaria* or *C. oryzae* may be used as test insects in assessing the effectiveness of fumigations of large bulks of grain. Frequently parts of these bulks are heating with temperatures rising to a maximum in the region of 42°C and it is therefore necessary to know whether these temperatures are too high for effective use of these test insects. Laboratory tests have been made with both species at 40, 37, 35, 32 and 25°C (as control) and 70 per cent R.H. using exposure periods of 5 and 10 days. Two cultures of each species were used, one containing the older larvae, pupae and some adults within grains, the other containing eggs and young larvae. All samples were kept at 25°C and 70 per cent R.H. before and after exposure. The emergence of adults was recorded. There was no significant difference between the results obtained at 25°C and at 32°C and they were combined to give figures upon which the emergence from a sample exposed at a higher temperature could be expressed as a percentage survival. At 40°C there was almost no survival. At 37° and 35°C considerable reductions in emergence were found but *C. Oryzae* was less affected than *C. granaria* and the younger stages of both species were less affected than the older. At 37° and 35°C there was also a marked delaying effect on emergence.

Similar tests will be required on other species to discover whether any other type of test insect would provide a more reliable assessment of the effectiveness of the fumigation when temperatures are above about 32°C and exposure periods are long. (*Miss B. D. Hole*).

BIOCHEMISTRY

The event of the year for the biochemistry section was the occupation of the new biochemistry building. This was formally opened by Sir Ben Lockspeiser on the 6th November, 1953 (see Plate I). The building consists of nine laboratories, dark room, cloak rooms, etc. Two principal end-laboratories provide for "semi-hot" radiobiological and radiochemical work respectively. Many features of the laboratory such as the design of the fume chamber units, mounting of all service points and controls clear of work-bench surfaces were based directly on the experience gained by the section in the use of radioactive tracer techniques. During construction of the building there was a close and successful co-operation between the scientific and Ministry of Works personnel concerned. The move unavoidably brought to a standstill almost all the work of the section for a time. Much of the apparatus (e.g. Warburg respirometer, Geiger counting assemblies, etc.) has now been re-assembled however, (December, 1953) and the research programme has been largely resumed. Cleaning and maintenance of the building, and provision for the rigid control of the hazards associated with the use of radioactive substances have been fully organized. The new building will greatly enhance the efficiency of the work of the whole section but in particular it has eliminated the difficulties of rigidly controlling the radiation hazards which obtained under the exceedingly cramped conditions of the old laboratories.

Mr. S. E. Lewis returned to the section in October, 1953 having spent a profitable year at the Molteno Institute, Cambridge, studying enzyme techniques by a special arrangement with Professor D. Keilin.

Mr. D. I. Packham (D.S.I.R. Treasury Bursary student) spent two months doing vacational work in the section. He took part in the studies on the action of insecticides on the phosphorus metabolism of insects.

During the year there has been an increasing number of visitors to the section. There has been a growing interest in the uses of radioactive tracers for studying insect migration problems in the field. Advice was sought, and given whenever possible, on such problems as tagging mosquitoes, tsetse flies, strawberry beetles and ants.

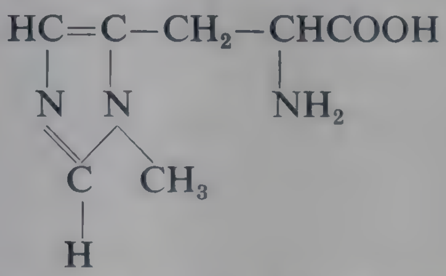
As previously, the work of the Section has been summarized under three headings, A, B, and C, as follows:

A.—Studies on the nature and significance of insecticide residues in foodstuffs

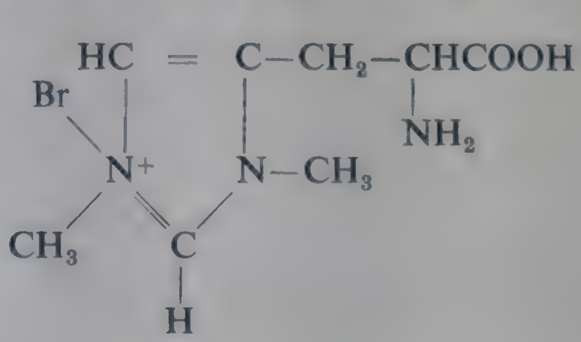
METHYL BROMIDE RESIDUES IN FUMIGATED WHEAT

The research into the nature of the chemical reactions between wheat and methyl bromide under the conditions of fumigation has been completed by the identification of the N-methylated derivatives.

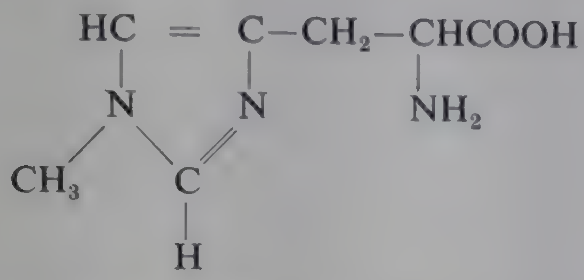
Potato-starch chromatographic analysis of the acid hydrolysate of wheat protein fumigated with methyl bromide showed that only three N-methylated compounds, all derivatives of basic amino acids, were present in appreciable amounts. These were resolved satisfactorily on a paper chromatogram using a phenol solvent saturated with a buffer solution of pH2. The three basic amino acids arginine, histidine and lysine were methylated under aqueous conditions when the alpha-amino group is unattacked. The resulting mixtures of N-methylated amino acids were co-chromatographed on paper with a hydrolysate of wheat protein fumigated with C^{14}— labelled methyl bromide. X-ray plate autoradiographs of the resulting strips were made which, on development, revealed the positions of the active amino acid derivatives. The added methylated amino acids were detected by their colour reaction with ninhydrin. Complete coincidence of the activity and colour areas occurred only with the three derivatives produced on methylating histidine.

1-Methyl histidine,  has been synthesised following the method of Sakami and Wilson [*J. Biol. Chem.* 1944, **154,** 215]. This has proved to be identical with the methylated derivative obtained from the fumigated protein which runs slowest on a paper chromatogram.

1-Methyl histidine on further methylation gives a compound identical with the fastest running derivative. This is presumably the dimethyl quaternary compound



Initial experiments indicate that the third histidine derivative on further methylation also gives the same quaternary compound and yet is itself not derived from methylation of 1-methyl histidine. It must therefore be the mono methyl isomer, 3-methyl histidine



There is evidence from the published literature that dl 1-methyl histidine is not toxic to white rats although it does not replace histidine when fed to rats on a histidine deficient diet. Work is at present in progress to examine the toxicity of the other methylated histidines. (*R. G. Bridges*).

B.—Studies on insecticidal action mechanisms

SEPARATION AND IDENTIFICATION OF ACETYLCHOLINE IN INSECTS

In order to obtain further evidence for the identity of the acetylcholine-like substances found in insect tissue, extracts from the blowfly (*Lucilia sericata*) have been studied by paper-chromatographic methods. The only biologically-active substance found on the chromatogram possessed an Rf value equal to that of acetylcholine. An extract from large numbers of flies has been obtained which contains several milligrams of the acetylcholine-like substance as assayed on the frog muscle preparation. A crystalline derivative is being prepared from this extract in order to provide a complete identification. (*S. E. Lewis, K. S. Fowler*).

ACETYLCHOLINE IN INSECTS

A survey has been made of the acetylcholine content of various insect tissues, using the frog rectus abdominis preparation as a method of assay. Generally the amount found was in proportion to the nervous tissue present. Whole larvae of *Lucilia sericata* and *Tenebrio molitor* contained 0·1–0·2 μg/g (wet weight); whole flies (*Lucilia sericata*) about 1 μg/g, most of which was in the head and thorax. Ventral nerve cord of the cockroach (*Periplaneta americana*) contained about 19 μg/g.

Some results have been checked by using different methods for extracting the acetylcholine, particularly with *Periplaneta* for which figures have been published in relation to DDT poisoning. The figure given above is about half the published value, and has been obtained by two different methods of extraction.

Large amounts of an acetylcholine-like substance were found in the crop of *Lucilia* larvae, but this appears to be due to the presence of a similar substance in the liver on which they feed.

Assays have also been carried out on eluates from paper chromatograms used in connection with the separation and identification of acetylcholine-like substances. (*S. E. Lewis, Mrs. B. G. Patterson*).

CHOLINESTERASE ACTIVITY IN INSECTS

In a study of the cholinesterase activity of the blowfly (*Lucilia sericata*) a

search for the enzyme in the egg or in the larva was negative. Cholinesterase activity is developed soon after pupation and increases regularly throughout the pupation period, reaching a maximum at the time of emergence. The enzyme activity was estimated by the increase in CO_2 production from a bicarbonate buffer in the presence of acetylcholine as substrate; considerable variation was observed in the controls in the absence of acetylcholine. In the absence of acetylcholine the CO_2 production rises to a maximum in 3-day larvae and then falls to an insignificant level at the time of pupation. This CO_2 has not so far been accounted for by lactic acid production or by phosphate ester hydrolysis, nor was it apparently associated with the crop contents.

Cholinesterase activity has now been demonstrated in preparations from heads of *Tenebrio molitor*, in the whole larva and in the prepupa.

No evidence has been obtained for the existence of a natural inhibitor in extracts from *Tenebrio* heads, as was suggested in an earlier report, although Lord & Potter have recently reported that such an inhibitor may be present in extracts of *Tribolium castaneum* adults. (*S. E. Lewis, Miss M. K. Winckler*).

EFFECT OF INSECTICIDES ON THE METABOLISM OF PHOSPHORUS BY INSECTS

Work under this heading has continued during the year, attention being directed to the normal phosphorus metabolism of insects before studying the effects of insecticides and fumigants thereon. On the basis of their behaviour under the conditions of paper chromatography, rates of hydrolysis, products of hydrolysis etc., the following compounds have been identified and determined in the thoracic muscle of the housefly:

Adenosine triphosphate
Adenosine diphosphate
Arginine phosphoric acid
Glucose—6—phosphate
Phosphoglyceric acid
Orthophosphate

Arginine phosphoric acid is present in much smaller quantity than that reported by Meyerhof in his classical work on the Arthropoda. These results suggest that apart from phosphagen content the metabolism of soluble phosphates in the housefly is not very different from that of mammalian tissues.

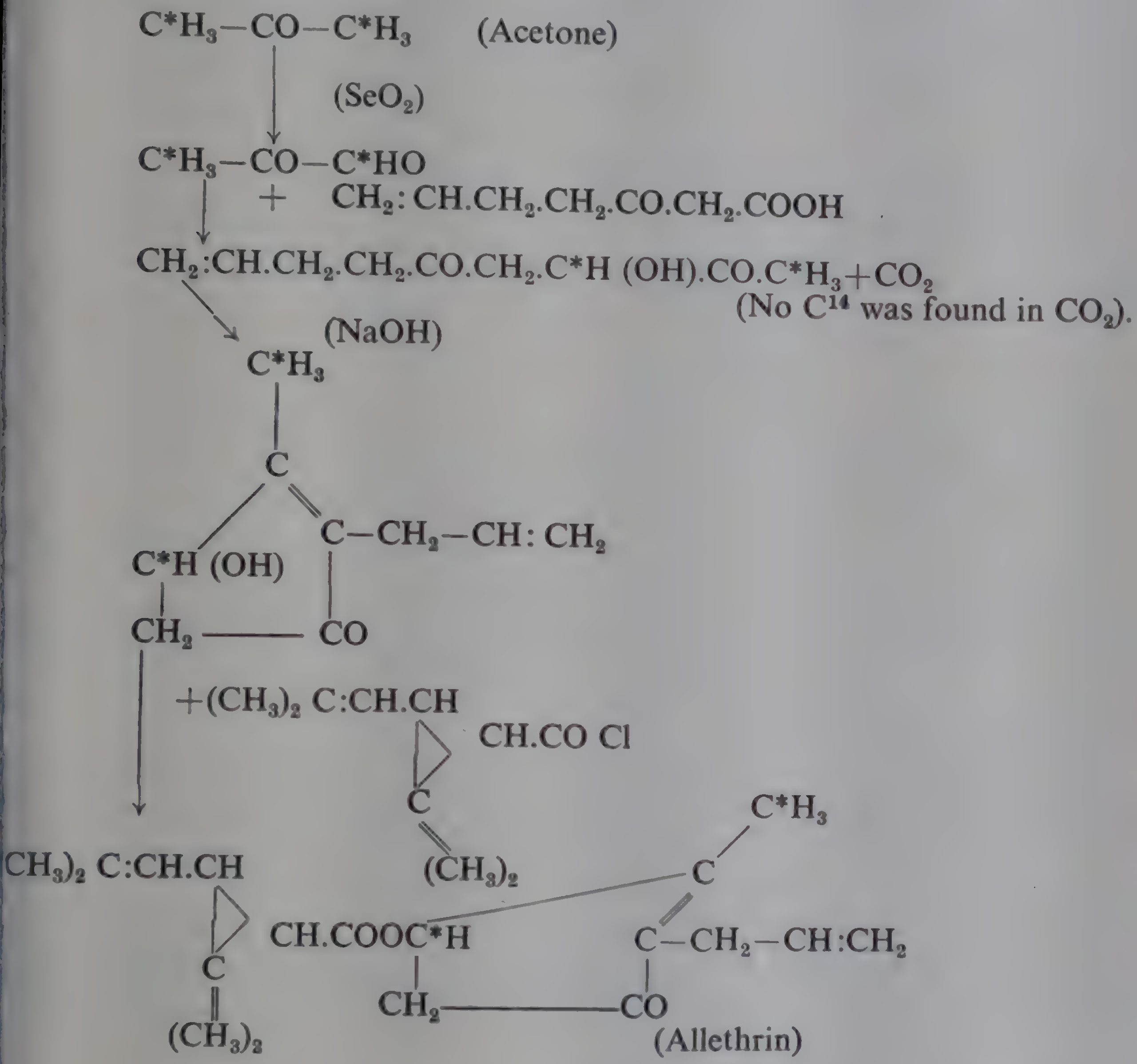
Autoradiographic studies have demonstrated high concentrations of phosphorylated intermediates in the gut wall of the housefly. Qualitatively the distribution of these phosphorus compounds was similar to that of the muscle. This suggests that the glycolytic cycle is operative in the transport (e.g. of carbohydrate) across the gut wall. A high concentration of phosphorus compounds was similarly demonstrated in the Malpighian tubules of houseflies but appears to contain a higher concentration of orthophosphate than was found in the gut. (*F. P. W. Winteringham, Mrs. P. M. Bridges, G. C. Hellyer*).

C.—Miscellaneous work fundamental to A and B

SYNTHESIS OF ALLETHRIN LABELLED WITH RADIOACTIVE CARBON —14

In order to study the mode of action of the pyrethrin-type insecticides the preparation of allethrin (an allyl homologue of Cinerin I) labelled with radioactive carbon —14 was undertaken in 1951. The first stage of this work was completed in the Insect Toxicology Laboratory of the University of California, Berkeley, Ca., in 1951 and was greatly facilitated by the generous gift of certain intermediates

by Dr. S. H. Harper of King's College, London. This project was completed during the current year by the preparation of about 400 milligrams of crude radioactive allethrin. By means of reversed phase paper chromatography the ester has been isolated in a high state of purity from the crude sample. The specific activity of the pure ester is estimated to be of the order of 100 microcuries per gram. The pure ester will be used for studying its metabolic fate in insects, particularly from the point of view of resistance and synergism mechanisms. The labelled material was prepared by the following route, asterisks denote the positions of radioactive carbon atoms:



(*F. P. W. Winteringham, A. Harrison*).

COLONIAL LIAISON

The volume of correspondence with colonial territories has steadily increased until during 1953—seventy letters (average) a month were received.

During the year there were sixty-eight visitors from the colonies and eighteen from the U.K. to discuss colonial problems.

Four courses on food storage problems have been organized with the Infestation Control Division, Ministry of Agriculture and Fisheries, at which thirty

officers from sixteen territories attended. Arrangements have now been mad with the Ministry to give this Course three times a year.

The Laboratory has been able to investigate a number of *ad hoc* problem about which information is required before advice can be given to the territorie concerned. This has been facilitated by the appointment in April 1953 of Mis P. M. Davey (Experimental Officer) as research assistant to the Colonial Liaiso Officer. In addition, several problems of a more fundamental nature have bee investigated with the active collaboration of other sections of the laboratory, th Colonial Products Advisory Bureau, the National Institute of Agricultura Engineering, the Building Research Station and the Road Research Station o the Department of Scientific and Industrial Research, and the Ministry o Agriculture and Fisheries.

REPORTS

The following reports have been prepared and distributed:

(a) Food storage in Kenya
(b) ,, ,, ,, Uganda
(c) ,, ,, ,, Tanganyika
(d) ,, ,, ,, Zanzibar
(e) ,, ,, ,, Gambia
(f) ,, ,, ,, Sierra Leone
(g) Bruchid beetles or " fly " in beans
(h) Fumigation using chlorinated hydrocarbons
(i) Assessment of degrees of infestation in Colonial territories
(j) Quality of Gambian groundnuts with special reference to insect infestatio
(k) Present condition of Nigerian groundnuts
(l) Comparison of quality of " new " and " old " crop Nigerian groundnut

(*D. W. Hall*

ADVISORY WORK

Storage schemes, disinfestation measures, etc., specially suited for loc conditions have been devised and sent to the territories concerned. Many the enquiries received have concerned the use of fumigants, the merits of differe types of grain drying machinery and moisture determination meters, the uses various forms of storage buildings, and the use of different contact insecticide

In a number of territories a considerable advance in stored products work taking place. This can be indicated by quoting some of the major development

S. Rhodesia

Provision for circulatory fumigation in a large silo to be erected in Salisbu was recommended by the Colonial Liaison Officer while on tour. The bi were large, 1,000 tons each, with side outlets at the bottom, presenting pecul problems of gas distribution. A detailed scheme has been drawn up by t Fumigation Section of the Laboratory and is being implemented.

Nyasaland

Maize is heavily infested with insects when it is brought into storage depo A recommendation to adopt fumigation of maize stocks with methyl bromi under gas proof sheets has been acted upon.

Bechuanaland

A scheme for storage of 10,000 tons in cheap horizontal bulk storage premises of the type now being experimented with in the Union of South Africa has been put before the authorities.

Nigeria

New methods of storage for groundnuts have been suggested to the West African Pest Infestation Research Unit for experimentation. These are being investigated.

Investigations have been made into the development of improved gas proof sheeting material for the disinfestation of groundnut pyramids. Neoprene coated cotton, and neoprene, butyl and plastic coated nylon fabrics are being tested in collaboration with the Ministry of Supply.

Gold Coast

A tentative storage scheme to provide for storage at the main centres and for amine reserve (in underground pits) in the North has been put before the uthorities.

Sierra Leone

Recommendations that a stored products entomologist should work on local ice storage problems have been accepted by the Sierra Leone Government.

anganyika

There are now two European officers who have been trained in the U.K. in the echnique of fumigating foodstuffs, and large tonnages are being treated successully. A pamphlet, for distribution to farmers (European and African) at Agricultural Shows, on "Insects that Attack your Grain" was prepared in ollaboration with the Infestation Control Division, Ministry of Agriculture and isheries.

Tanganyika is embarking on full scale storage of grain in underground pits—otal pit storage in 1954 will be 4,000 tons.

PECIAL INVESTIGATIONS

uality of groundnuts exported from West Africa

The Colonial Products Advisory Bureau have been concerned with assessing e quality of groundnuts grown in the Gambia and in Nigeria. Since insects ause considerable damage to groundnuts from both these territories the aboratory collaborated in these investigations. The results indicate the eriousness of insect pests:

The Gambia

(a) Damage to the samples of Gambian groundnuts examined may be conveniently grouped into pre-harvest and post-harvest damage.

(b) Pre-harvest damage by insects (and possibly fungi) was found in 1·2 per cent-10·8 per cent (average 5 per cent) of the nuts.
Post-harvest damage by insects was found in a further 2·4 per cent-16 per cent (average 5 per cent). The percentage of nuts damaged by

insects (and possibly fungi) before and after harvest was about 10 per cent.

The percentage of nuts damaged by means other than insects was about 7 per cent.

The percentage of immature nuts was about 18 per cent. The total percentage of light weight nuts was about 35 per cent.

(c) Weight loss due to the attack of insects (and possibly fungi) was about 3 per cent (in some cases as high as 6-9 per cent) equivalent to 1,650 tons on the 1952-53 Gambian crop of 55,000 tons, on a loss of some £90,000. This figure excludes loss in weight resulting from immature nuts.

Nigeria

(a) Infestation by insects of groundnuts stored in Nigeria results in serious pulverisation of the nuts, broken nuts being especially liable to insect attack.

(b) Breakage and pulverization of the nuts results in serious increases in the percentage of free fatty acid (F.F.A.).

QUALITY OF OIL OBTAINED FROM DUST, BROKENS, AND WHOLES AND HALVES FRACTIONS OF "NEW" AND "OLD" CROP NUTS

Fraction	New Crop			Old Crop		
	% Oil	Acid value mg KOH per g of oil	Free fatty acid	% Oil	Acid value mg KOH per g of oil	Free fatty acid
Wholes & Halves	47·2	4·0	2·0	49·5	11·8	5·9
Brokens	44·2	14·6	7·3	46·2	35·1	17·5
Dust	21·9	137·6	63·8	16·0	109·2	54·6

(c) A 3 per cent reduction in the F.F.A. of nuts arriving in the U.K would mean a saving of some 9,000 tons of margarine. (*D. W Hall, Miss P. M. Davey*).

Water vapour barriers for floors of storage premises

One of the essentials in the proper storage of commodities is to prevent th passage of water vapour through the floor. Since many existing storage premise or godowns have floors which are not water vapour proof it has been necessar to use dunnage to provide a gap between the commodity and the floor. Variou methods of proofing existing warehouse floors to eliminate the need for dunnag are being investigated in collaboration with the Grain Storage Section of th Pest Infestation Laboratory, and Road Research Laboratory. Each test last about six months, and to date it has been shown that prefabricated bitumenize surfacing (P.B.S.), developed during the war and used on aircraft runways, is suitable material. Strips of this material can be easily and effectively joine using petrol or cut back bitumen. A number of other materials are bein tested. (Plate III(A)). (*D. W. Hall, Miss P. M. Davey*).

Underground pits

There is a very wide scope in Colonial territories for the use of this method of storage, especially for famine reserves. Experimental pits are being tested in Tanganyika, Nigeria, and Nyasaland and the results of some of these experiments indicate the need for improvements possibly in design as well as construction. The collaboration of the Building Research Station has been sought, and details of improved methods of constructions are being considered. (*D. W. Hall, T. A. Oxley*).

Conditions of carbon dioxide and oxygen which are unfavourable for the survival of the rice weevil (Calandra oryzae)

Modern methods of airtight underground pit storage depend for success for controlling insect infestation on the fact that insects present in the grain rapidly convert the oxygen in the intergranular air into carbon dioxide and kill themselves by the products of their own respiration. A series of experiments were planned to show:

(a) The effect of high concentrations of carbon dioxide with the oxygen at high concentrations.

(b) The effect of oxygen deficiency.

(c) The joint effect of low oxygen and high carbon dioxide tension.

Adult Rice weevils can survive in concentrations of carbon dioxide up to 15 per cent when the oxygen concentration is maintained at a high level.

The concentration of carbon dioxide produced by *C. oryzae* adults in hermetically sealed conditions reached a maximum of 18 per cent at 25°C. At this concentration the beetles died. In these experiments the minimum oxygen concentration obtained was 0·8 per cent.

When the carbon dioxide produced is absorbed by caustic potash the weevils use up approximately all the available oxygen at the rate of 0·15 ml. per day before dying. Therefore it would appear that it is the oxygen deficiency rather than the carbon dioxide concentration which is the operative factor causing the death of the insects in underground pits. (*D. W. Hall, T. A. Oxley, Miss E. Reynolds, Miss P. M. Davey*).

Susceptibility of paddy and rice to attack by insects

Rice production in many territories is increasing and very little is known about the importance of different insect pests during storage. In particular, knowledge is required of the susceptibility of paddy and rice to the attack of different insect species.

A preliminary experiment was set up to find whether *Sitotroga cerealella, Calandra oryzae, Rhizopertha dominica, Laemophloeus minutus, Oryzaephilus surinamensis* and *Tribolium castaneum*, previously bred on wheat, would survive and breed on three types of rice and two types of paddy. It was found that *Sitotroga cerealella* survived and bred on paddy and rice; *Calandra oryzae* survived and bred best on unpolished rice but would survive and only reproduce to a limited extent on paddy and polished rice; *Rhizopertha dominica* survived fairly well and maintained itself on paddy as well as on unpolished rice; *Tribolium castaneum* maintained itself to a limited extent on unpolished rice but not on paddy; the remaining insects did not survive on rice or paddy. There are indications that *Calandra oryzae* and *Rhizopertha dominica* that have been

bred on rice attack paddy much more readily than insects previously bred on wheat. (*D. W. Hall, R. W. Howe, Miss P. M. Davey*).

Filth contamination in maize meal

Maize is the staple food of Africans in many parts of Africa. When the maize is harvested, it is often already infested with weevils and moths, and during storage flour beetles and other insects join in the destruction and contamination of the grain. In addition in certain regions rodents infest the stacks of stored grain The hammer mill was introduced into many territories to provide maize meal and this method has largely replaced the old method of winnowing the grain and grinding between stones or by pestle and mortar With the hammer mill the maize and contained insects etc. are ground up and the resultant meal is often stated by Africans to be less appetising than that produced by their women-folk and is sometimes claimed to cause stomach upsets. In East Africa the quality of maize meal is based on a test which measures phosphate acidity.

Samples of maize meal from East and Central Africa were collected during my tours and analysed for filth contamination by the British Baking Research Association, The British Food Manufacturers Research Association and the Cereal Research Laboratory in the U.K. The results showed that there were up to 22,000 insect fragments and up to 70 rodent hairs per 25 gm. of mea (i.e. in an egg-cupful of meal). (*D. W. Hall*).

Effect of attack of three species of beetle on the protein of groundnut

Mention has been made of the high degree of insect infestation to which Wes African groundnuts are subjected during storage in Africa. During the pas two or three years stress has been placed on the need for improved protei quality of groundnuts destined for the manufacture of " Ardil." The bes groundnuts for this purpose are those which are hand shelled, and unbroken Groundnuts in storage attacked by insects are pulverised to a greater or lesse extent with a probable detrimental effect on the protein quality of the nuts The collaboration of the Colonial Products Advisory Bureau was sought and a preliminary experiment set up, exposing whole kernels (hand shelled) to th attack of light infestations of *Tribolium castaneum*, *Trogoderma granarium* (tw serious pests of decorticated nuts in Nigeria) and a heavy infestation of *Caryedo fuscus* (a serious pest of undecorticated nuts in Gambia) for 8 weeks at 27°C an 70 per cent relative humidity. The results indicated a loss in extractable protei of 2·1 per cent in the case of *Tribolium castaneum*, 3·9 per cent in the case c *Trogoderma granarium* and 1·8 per cent in the case of *Caryedon fuscus*. Thi work is being continued. (*D. W. Hall, Miss P. M. Davey*).

Comparison of various types of moisture meters

This work has been carried out in collaboration with the Grain Storag Section of the Laboratory, and had three main objectives:

(a) To compare the efficiency of a number of methods suitable for field u against a standard oven method.

(b) To compare the results obtained by different temperature/time combinatio on a standard oven method.

This work indicates that the result obtained using an air oven at 113° (or 120°C) for 4 hours is very comparable with that obtained at 130° for 1 hour.

(c) To calibrate a new moisture tester being developed at the laboratory. (See p. 14). (*D. W. Hall, Miss P. M. Davey*).

LIBRARY

The library now contains 780 books, about 6,400 pamphlets, 61 Annual Report series and 144 periodicals, several of the last mentioned being in duplicated form. Acquisitions during 1953 included 100 books, 526 reprints and 260 reports, translations, etc., and eight periodicals.

73 periodicals are now seen on regular loan (as opposed to 71 in 1952). 525 items were borrowed from other libraries in response to special requests from laboratory staff, and 350 items lent outside the laboratory during the year.

All periodicals seen in the library are read and indexed and relevant articles are brought to the attention of research staff concerned. The total number of items indexed during 1953 (including acquisitions, loans, and information from abstracts) was 3,240.

APPENDIX I

Papers Published in 1953

1. Brown, W. B. and Heuser, S. G. Behaviour of Fumigants during Vacuum Fumigation. I. Penetration of Methyl Bromide into Boxes of Dates. *J. Sci. Fd. Agric.*, 1953, **4** (1), 48-57.

2. Brown, W. B. and Heuser, S. G. Behaviour of Fumigants during Vacuum Fumigation. II. Penetration of Methyl Bromide into Bagged Wheatfeed, and related Diffusion Experiments. *J. Sci. Fd. Agric.*, 1953, **4** (8), 378-386.

3. Clegg, K. M. and Lewis, S. E. The Vitamin-B Content of Foodstuffs fumigated with Methyl Bromide. *J. Sci. Fd. Agric.*, 1953, **4** (11), 548-552.

4. Green, A. A. Blowflies: a Community Problem. *Sanitarian, Lond.*, 1953, **61** (9), 362-368.

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APPENDIX II

Staff of the Pest Infestation Laboratory
1953

Director of Pest Infestation Research: G. V. B. Herford, O.B.E., M.Sc.
Assistant Director: E. A. Parkin, D.Sc., Ph.D., M.Sc., D.I.C.

COLONIAL LIAISON

Colonial Liaison Officer: D. W. Hall, B.Sc.
(*Senior Scientific Officer*)
Experimental Officer: Miss P. M. Davey, B.Sc.

BIOLOGY SECTION

Principal Scientific Officers: M. E. Solomon, M.Sc., R. W. Howe, B.Sc., A.R.C.S.
Senior Scientific Officers: C. W. Coombs, M.Sc., G. E. Woodroffe.
Senior Experimental Officer: A. M. Cunnington.
Experimental Officer: Mrs. G. M. Blake, B.Sc.
Assistant Experimental Officer: H. D. Burges, B.Sc.
Assistants (*Scientific*)*:* B. J. Southgate; Miss J. E. Currie; Miss B. E. Adamson; Miss S. M. Nightingale; Miss R. Borrett; Miss M. C. Jackson.

FUMIGANT SECTION

Principal Scientific Officer: W. Burns Brown, M.Sc., F.R.I.C., A.R.C.S., D.I.C.
Senior Experimental Officer: H. K. Heseltine.
Experimental Officers: S. G. B. Heuser; Miss E. M. Reynolds.
Assistant Experimental Officers: *R. B. Hedley, B.Sc.; Miss B. D. Hole: J. D. Pearson, B.Sc.; Mrs. B. M. Reynolds; †J. B. Waller.
Assistants (*Scientific*)*:* Miss M. F. East; Miss C. E. Thomas.

INSECTICIDE SECTION

Senior Principal Scientific Officer: E. A. Parkin, D.Sc., Ph.D., M.Sc., D.I.C.
Senior Scientific Officers: P. S. Hewlett, B.Sc.; J. A. Hope, B.Sc.; B. P. Moore Ph.D.; D. Phil., B.Sc.
Senior Experimental Officer: A. A. Green, M.B.E.
Scientific Officer: Mrs. P. J. Maycock, B.Sc.
Assistant Experimental Officers: G. T. Bills, B.Sc.; *Miss M. A. Cant, B.Sc. Mr. K. G. Gostick; *Miss K. D. Lambe, B.Sc.; C. J. Lloyd A. M. Simmonds.
Assistants (*Scientific*)*:* Miss C. Belcher; Miss D. G. Blackman; D. G. H Halstead; Miss M. J. Kane; Miss R. Phillips; †P. S. Tyler.

BIOCHEMISTRY SECTION

Principal Scientific Officer: F. P. W. Winteringham, F.R.I.C.
Senior Scientific Officer: S. E. Lewis.
Senior Experimental Officer: A. Harrison.

cientific Officer: R. G. Bridges, B.Sc.
xperimental Officer: K. S. Fowler, B.Sc., A.R.I.C.
ssistant Experimental Officers: Mrs. P. M. Bridges, B.Sc.; G. C. Hellyer; ‡J. P. Heslop, B.Sc.; Mrs. B. G. Patterson, B.Sc.; Miss M. K. Winckler.
ssistants (Scientific): *Miss P. M. Heaton; Miss A. Weatherley.

FOOD STORAGE

rincipal Scientific Officer: T. A. Oxley, B.Sc., A.R.C.S.
enior Scientific Officer: Miss M. B. Hyde, M.Sc.
ssistant Experimental Officers: G. Ayerst; ‡R. W. Disney.
ssistants (Scientific): †D. Budd; Miss G. Wickenden; Miss M. Keeping.

PHOTOGRAPHY

enior Photographer: J. H. Hammond, A.R.P.S.
hotographer: Miss A. M. Stott.

GLASSBLOWER

enior Assistant (Scientific): A. E. Broughton.

LIBRARY

xperimental Officer: Miss H. C. N. Turnbull, M.A.
ssistant Experimental Officers: Miss C. M. Barber, B.Sc.; Miss S. G. Rawle, B.Sc.
lerical Officer: Miss B. A. Kent.

OFFICE STAFF

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lerical Officers: T. F. Morgan; Miss M. M. Wood.
emporary Clerk III: Mrs. B. D. Bell.
ypists: Miss E. Chadwell; Miss L. E. Ranscombe.
elephonists: *Mrs. M. J. Dinning; A. E. Janaway.

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strument Maker: M. A. Cordaroy.
tter: W. Wood.
arpenter: J. Gray.
river: R. Bateson.
orekeeper: E. A. Wiggins.
ardeners: A. O. Moss; A. Mills.
eaners: Mrs. Williams (Caretaker); Mrs. Waters; Mrs. Hitchcock; *Mrs. Bailey; Mrs. Eschle; Mrs. Rees; Mrs. Rodgers.

* Resigned in 1953.
† On National Service.
‡ Treasury Bursary.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

REPORT OF THE PEST INFESTATION RESEARCH BOARD

WITH THE REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH

FOR THE YEAR 1954

LONDON: HER MAJESTY'S STATIONERY OFFICE
1955

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31st December, 1954

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Department of Scientific and Industrial Research
Charles House, 5–11, Regent Street,
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* Resigned during 1954

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REPORT OF THE PEST INFESTATION RESEARCH BOARD FOR THE YEAR 1954

To the Lords of the Committee of the Privy Council for Scientific and Industrial Research

MAY IT PLEASE YOUR LORDSHIPS,

WE, the Pest Infestation Research Board, beg leave to present a report on our proceedings during the year 1954. The Report of the Director of Pest Infestation Research for the same period is appended.

There have been certain changes in the membership of our Board during 1954; the following members and assessors retired: Mr. W. H. Cashmore, Dr. T. Moran, Prof. O. W. Richards, Dr. J. W. Evans, Mr. N. M. Tulloh, Dr. J. R. Nicholls, Mr. E. J. Cowles, Dr. E. Marsden. The following appointments were made: Dr. F. H. Banfield, Dr. J. W. Corran, Dr. A. B. P. Page, Dr. R. Spence, Mr. G. Samuel, Dr. I. Thomas, and Dr. H. M. Elliott.

We have been giving considerable thought to the work of the Pest Infestation Laboratory in relation to current problems. The Laboratory came into existence in 1940, and although the need for it had arisen in the pre-war years its early work was directed towards the solution of critical war time problems. These principally centred around the conservation of large stocks of cereals in an insect-free condition. With the passage of time the problems have increased in variety, but the protection and treatment of bulk cereals has remained an important part of the research programme up to the present time.

Today the picture is changing. With the almost complete cessation of Government ownership and bulk purchase of foodstuffs, it is possible that the quantity of grain and other foodstuffs held in store in the country will decrease, and that with trading practice approximating to pre-war conditions, there may be a relatively rapid turnover of commodities. Such changes in food handling policy would bring certain infestation problems into greater prominence while others would become of less immediate importance in this country.

We have had in mind the need for a proper balance in the work of the Laboratory between basic research and shorter term investigations, and we believe that, with the staff at present available the relative effort devoted to these two objectives is reasonable. It should, we think, be possible for the Laboratory to keep abreast of new problems arising from changing conditions, without disturbance of long term research on the disinfestation and protection of particular foodstuffs, especially of grain held in bulk storage.

We consider that this field of research is of importance for two reasons. In this country it is impossible to forecast whether a sudden change of circumstances might at some future time necessitate food storage on a large scale over long periods, in which event it would be essential to have the most complete

background of relevant scientific knowledge. Many countries in the Colonial Empire and the Commonwealth are becoming increasingly concerned with bulk storage of cereals over long periods, for famine reserves or other purposes. Although the background of information now available in the Pest Infestation Laboratory is proving of great value in this field, new problems, or variations of existing problems are clearly demonstrating the need for a continuation of research on this subject.

We are glad that there has been no tendency to restrict the work of the Laboratory to problems which are solely and immediately concerned with the welfare of the United Kingdom. The importance of increasing the world's food production is equalled by the need to conserve harvested crops from destruction by pests and we feel that the Laboratory should play its part in this task by using its special experience and resources for the common good.

This might on occasion require some extension of the Laboratory's activities but it would usually take the form of advisory work or *ad hoc* investigations. The insect pests of stored products are limited in number, and are very widely distributed, the insects attacking grain, for example, in Britain being mainly those which attack it in Africa, India, or Australia, while cacao beans will be damaged by much the same insects in West Africa and the West Indies. On the other hand the behaviour of many of the insects varies according to the climate. For example, the Rice weevil and the Flour beetles, which only crawl in temperate countries, are strong flyers in the tropics and some measures which might successfully protect foodstuffs against them in London would be of little value in Kano or Kuala Lumpur. Moreover differences in climate and local requirements often involve differences in methods of food storage and handling, which, in turn, may necessitate modification of normal disinfestation practice.

Any effort by the Laboratory to assist countries overseas with their infestation problems must have an effect far beyond the point of application. Improvements which may result from such assistance are not only of local benefit, they are reflected in the quality of imported foodstuffs, upon which Britain has so largely to depend. This not only benefits the British consumer, but is also of particular advantage to food manufacturers and processors in this country, whose exports, especially to the United States, must maintain a high standard of freedom from contamination by insect fragments or rodent hairs, which are often introduced in imported raw materials.

To illustrate the variation in present standards and the room for improvement in food quality it may be noted that whereas the U.S. "tolerance level" is of the order of 40 insect fragments per lb of foodstuffs, some samples of African maize meal intended for local consumption contained up to 360 000 fragments in the same amount.

We draw attention below to a few items of current research selected from the Director's report, for their special interest or importance.

RESIDUES OF INSECTICIDES IN TREATED FOODSTUFFS

Public attention has been drawn to the lack of detailed knowledge concerning the effect of certain insecticidal chemicals in common use on agricultural crops and foodstuffs. To provide this type of information the residues formed in wheat after fumigation with methyl bromide have been investigated. Of these chemical residues, the greater proportion can be shown to be naturally occurring

constituents of common diet. Experimental and published data suggest that most of the remaining compounds would be quite innocuous at the concentrations found in practice after fumigation. It has been demonstrated, in work undertaken for the Laboratory by the Dunn Nutritional Laboratory at Cambridge, that such essential food constituents as certain B-vitamins are not significantly affected by fumigation with methyl bromide (p. 35).

FUMIGATION OF FLOUR WITH METHYL BROMIDE

During tests made in 1945 it was shown that although bagged flour could be fumigated with methyl bromide without effect on its baking quality, a slight foreign smell was sometimes detected in the freshly cut loaves. In consequence, the use of methyl bromide for the treatment of flour has been generally avoided, and indeed there have not been many occasions when flour intended for baking has required fumigation.

More recently, however, there has been renewed interest in the treatment of large stacks of bagged flour against insects, mites and rodents, and extensive tests have been carried out to determine whether any taint produced was of commercial significance. Samples of flour, fumigated under a number of different conditions, including an abnormally high dose, were submitted for tests to four laboratories, of which two were attached to commercial milling and baking firms.

As a result of these tests it has been concluded that no taint of commercial significance was present in any of the samples (p. 28).

BIOLOGY OF THE KHAPRA BEETLE

In Britain the Khapra beetle, *Trogoderma granarium*, is a serious pest in maltings, where it attacks even the dry, freshly kilned malt and thrives in the high temperatures commonly experienced. Control of this insect is difficult, partly because of its apparent resistance to insecticides and fumigants but perhaps chiefly because the larvae tend to secrete themselves for long periods, apparently without feeding, in inaccessible cracks in the structure of the malt bins, etc.

Following a detailed survey of infestation in a number of infested maltings, laboratory experiments are in progress to investigate more fully this tendency towards starvation by the larvae in the presence of unlimited food. It has become apparent that there are two types of larvae in any population, one of which proceeds through its period of feeding, moulting and growth without any abnormal interruption. The second type, on the other hand, undergoes a number of additional moults and feeding periods, together with one or more prolonged resting periods during which no feeding takes place. During these resting periods, when the larvae are hidden away in cracks, their oxygen consumption falls to an exceptionally low level, indicating a corresponding depression of normal bodily activity; this may permit of starvation for periods in excess of 18 months, and perhaps explains the high resistance to chemical control methods. A rapid increase of temperature will induce a proportion of these larvae to leave their cracks and seek food, as would be the case when an infested bin receives a new charge of hot, freshly kilned malt. The percentage of long-lived larvae present in a population appears to depend, not only on the degree

of crowding among the insects, but also on hereditary factors, though inbreeding experiments have so far failed to reveal any simple genetical relationship. (p. 9).

CONTROL OF ANTS IN HOSPITALS

Previous trials using the insecticide chlordane against Pharaoh's ant, *Monomorium pharaonis*, had shown that single buildings could be cleared and kept free of infestation, and had given valuable experience in selecting the most effective and economical method of application. Essentially, this involved painting continuous bands of insecticide along the base of all interior walls, around pipes, sinks, ovens, etc. in every room in the building, starting at the upper and the outer rooms and, clearing the ants from the outside towards the centre, thus preventing their dispersal. Acting on this principle, a large sanatorium, heavily infested throughout with *Monomorium*, was used for an experiment on a much larger scale. The sanatorium consisted of 17 separate wards and other buildings, with inter-communicating service ducts.

Treatment, applied again from the periphery to the centre, was undertaken by a team from the Laboratory staff, and proved completely successful. The estimated total cost, assuming labour to have been employed at current rates, would have been about £75 (p. 25).

In conclusion we are very glad that it has been found possible to agree to a steady expansion of the staff of the Laboratory over the next four or five years. We would, however, stress again the need for the provision of better and increased laboratory accommodation, a need which will be accentuated as the additional staff is recruited.

F. R. HORNE,

January, 1955 *Chairman*

REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH FOR THE YEAR 1954

GENERAL

1954 has seen the end of practically the whole of Government ownership of foodstocks, and with it the reversion from bulk buying to private trading. It will be interesting to observe the effect of these important changes on infestation problems. The close liaison which exists between the Laboratory and the Infestation Control Division of the Ministry of Agriculture and Fisheries should ensure that any new problems that may arise in this way are not overlooked.

A small expansion of staff was authorized during 1954, and was used to strengthen the Biology Section and to provide assistance for the Colonial Liaison Officer. It is most encouraging to note that further recruitment will be possible in the future, by the addition of five or six staff annually over the next four years.

During the past year there have been the following visits overseas by members of the staff: the Director visited West Africa and represented the Colonial Office at meetings in Lagos of a Committee set up to review annually the work of the West African Stored Products Research Unit. He also visited Sierra Leone and the Gambia to discuss infestation problems.

Dr. E. A. Parkin (Assistant Director) has continued as Chairman of the Larval Test Sub-committee of the Moth and Dermestid Beetle Proofing Committee, and attended an international meeting on this subject in Brussels.

Miss M. B. Hyde attended the Eighth International Botanical Congress in Paris, contributing a paper, and subsequently visited some of the French silos used for hermetic storage of grain, and certain research institutions in and around Paris.

Mr. T. A. Oxley spent nine weeks in Canada and the United States studying current research and practice in grain storage, during which he presented a paper on "Underground Storage of Grain" to the American Association of Cereal Chemists. Several weeks were occupied in studying the problems arising in the storage of large wheat and maize surpluses in the United States. Part of the visit was spent in the Southern States with Mr. D. W. Hall, the Colonial Liaison Officer, where particular attention was paid to the processing and storage of paddy and rice.

Earlier Mr. Hall had visited the British Colonies in the Caribbean area to determine local food storage problems.

Mr. A. A. Green, at the invitation of the Government of the Gambia, is spending about three months in that territory, with the object of reducing the present losses due to the infestation of harvested groundnuts.

Mr. H. K. Heseltine, together with Mr. R. H. Thompson of the Ministry of Agriculture and Fisheries, Infestation Control Division, visited Germany

during September to study developments in fumigation techniques, in particular the use of commercial preparations which evolve phosphine for the fumigation of grain in bulk on floors or in silo bins.

Mr. F. P. W. Winteringham and Mr. A. Harrison attended the Second Radio-isotopes Conference in Oxford, and demonstrated a 4-π Geiger counter technique.

Miss P. L. Robertson, who is working at the Laboratory as a Civil Service Research Fellow, visited Holland to study the Oudemans Mite Collection at the Natural History Museum, Leyden, and to observe the cheese-making industry in Holland, with particular reference to the prevention of mite infestation.

Dr. B. N. Smallman, principal entomologist of the Science Service Laboratory of the Canadian Department of Agriculture, spent three months at the Laboratory, working in the Biochemistry Section while on sabbatical leave.

BIOLOGY

Most of the work of the Biology Section up to date has been concerned with one or more of three types of populations of pests, which may be set out as follows:—

(1) Populations associated with buildings, but not in stored materials other than neglected residues. These include the fauna of certain birds' nests and bat roosts, and the " residual " populations found in the fabric of storage buildings. Their main significance is as sources of pests which may attack valuable materials in stores or houses. Recent and current investigations include studies of the distribution, abundance and interaction of such populations.

(2) Populations on stored materials, such as those of the Khapra beetle in malt and those of mites on stored cheese, referred to in the following Report. The main aspects studied are their distribution in relation to physical conditions, their behaviour, and their interactions.

(3) Populations of various species cultured and maintained in the laboratory for the study of their behaviour, their physical limits for survival, and their rates of development, mortality, reproduction, and net increase, under a range of physical conditions. The bulk of the work from year to year consists in the detailed study of such material.

Although conditions in stored materials are more stable than those out of doors, they are far from uniform; temperature and humidity conditions differ between parts of a bulk, and tend to change, though often slowly. Attempts have been made in past years towards bridging the gap between storage and constant laboratory conditions, on the one hand by means of experiments with small stocks or cultures in outbuildings, and on the other by means of cabinets in which the conditions fluctuate in a controlled manner. The latter project is still in its developmental stages.

The basis for a considerable development of work under experimental storage conditions has now been provided by the building of four small storage rooms in the grounds of the Laboratory. In one of these an experiment is in progress on the effect of an infestation on the temperature conditions in a small stack of

grain. In others, experiments are being set up for the study of the dispersal of pests, and of the changes in distribution and relative numbers of different species of insects in grain as a multiple infestation develops.

Another new project is a detailed survey of two or three farms, to be continued over several years. The farms will be treated as ecological units and the relative importance of insects in residues, sheds, birds' nests, hay ricks and those brought in on sacks or provender will be studied.

Of the items dealt with below, many are reported for the first time. Others are chiefly a continuation of work described in earlier Reports, notably the investigations on the Carpet beetle, the Khapra beetle, the Tyroglyphoid mites, and those on the systematics of Fungus beetles (*Cryptophagus*), on residual populations, and on the life histories and physical limits of various beetles.

As in previous years, the work of the Section has depended at many points on the indispensable assistance and co-operation of officers of the Ministry of Agriculture and Fisheries, Infestation Control Division, who have sent in many samples of infested material for study at the Laboratory, drawn attention to infestations suitable for study, and assisted in arrangements for field work.

RESIDUAL POPULATIONS OF INSECTS

Beneath a farm grain store

Mr. H. P. Smith, of the Infestation Control Division, of the Ministry of Agriculture and Fisheries, drew our attention to a store where the floor was raised above ground level and the area beneath was completely enclosed. On examination it was found that grain had fallen through cracks in the floor and accumulated beneath. Mounds of fresh grain were found upon older grains and these intermingled below with soil. Vertical core samples were taken and the condition of the residues and the numbers of the insects present were noted.

The residues were classified by visual examination and by the relationship between the weight-volume ratios before and after sieving through a 1/10 in. mesh. By means of this classification, samples from different cores could be compared. The insects present included a number of grain pests (mainly the Grain weevil, *Calandra granaria*, the Saw-Toothed Grain beetle, *Oryzaephilus surinamensis*, and the Brown House Moth, *Hofmannophila pseudospretella*) and their parasites, and also various fungus feeders and ground dwellers. The distribution of these insects seemed to be governed to a large extent by the condition of the residues and the depth below the surface.

In a disused water mill

This mill had not been used as such for at least ten years, and the residues in the storage bins consisted mainly of empty glumes and finely divided material. Very small numbers of the following species were found:—

> The Brown House moth, *Hofmannophila pseudospretella*, the Window fly, *Scenopinus fenestralis*, the Fur beetle, *Attagenus pellio*, a moth, *Tinaea* sp., a Carpet beetle, *Anthrenus fuscus*, the White-marked Spider beetle, *Ptinus fur*, the Silverfish, *Lepisma saccharina*, and a beetle, *Corynetes coeruleus*.

The mites *Tyroglyphus farinae* and a species of *Glycyphagus* were also found. Other examinations of residues and birds' nests in a reduced condition have

revealed the presence of *Attagenus pellio* and *Scenopinus fenestralis* when little or no other life is present.

A squirrel's drey in the roof contained a larva of *Attagenus pellio*, a larva of *Anthrenus fuscus*, one adult of each of the fungus-eating beetles *Cryptophagus scanicus* and *Mycetaea hirta*, and the mite, *Tyroglyphus farinae*.

In disused dock storage sheds

Six large single-storey sheds on a dockside were examined. Where cavity-walls were present, the cavities were open at the bottom to the outside, and any grain penetrating the wall cracks fell through to the ground where it was exposed, and so did not serve as a reservoir of food. Residues scraped from between the horizontal wall boards consisted largely of webbing and cocoons with only a small quantity of food material. *Hofmannophila pseudospretella* and *Tyroglyphus farinae* were everywhere common, and *Oryzaephilus surinamensis* and the Fungus beetles *Cryptophagus* spp. were present in some numbers. There were three species of *Cryptophagus*, one the common *C. saginatus* and the other two *C. obsoletus* and *C. simplex*, only recently reported in Britain. Only a few larvae of the Cacao moth *Ephestia elutella* were found, but this was not unexpected since adults were emerging during the visit and larval migration had probably already taken place. If the areas sampled were typical, then an appreciable residual population was present in the cracks, but, as there was little food material, the prolonged survival of large numbers was unlikely.

Residues collected from beneath the floor boards were practically sterile, e.g. two 12 in. by 7 in. sample-bags full of residue from one shed yielded only one *Calandra granaria* and no other living insect or mite. The residues consisted mainly of glumes and finely-divided material and a large population was not expected, but such a degree of sterility as was found is difficult to account for except possibly as the result of previous insecticidal treatment. (*C. W. Coombs, G. E. Woodroffe, B. J. Southgate*).

FAUNA OF BAT ROOSTS

Two enquiries received from householders concerning the eradication of bats from their premises provided opportunities for studying the insects and mites associated with the dung which accumulates in their roosts. The fauna of this material was found to be closely similar to that of birds' nests in similar situations (see *Pest Infestation Research*, 1951, pp. 8–9). The following points are of particular interest:—

A rare Spider beetle, *Mezium affine*, occurred in large numbers in one of the roosts. There are very few records of its occurrence outside warehouses.

Larvae of the Varied Carpet beetle, *Anthrenus verbasci*, were present in very large numbers in one of the roosts.

Five examples of a parasitic bug were captured. Three of these were the well-known *Cimex pipistrelli* but two were *C. dissimilis*, a species for which only two British records exist, and these are very old and of doubtful authenticity.

One of the commonest mites present was an undescribed species of *Nycteriglyphus*.

The common predatory mites, *Cheyletia flabellifera* and *Acaropsis docta*, were present in some numbers and appeared to have been sucking the blood of

the bats. This is an unexpected habit in normally predatory species. (*G. E. Woodroffe, B. J. Southgate*).

BIOLOGY AND BEHAVIOUR OF THE KHAPRA BEETLE

Populations in maltings

The general survey of maltings has been suspended in favour of a more detailed study of populations at two selected maltings.

Sampling and trapping have shown that many of the larvae entering new malt and of those in well-developed infestations move to the highest point in the bulk.

When one malting was emptied the distribution of larvae in cracks was largely determined by the temperature distribution and the way in which the malt was put in and removed. Cracks in the walls just below the original surface of the malt, around the beading, and in the wooden floors were heavily populated.

Larvae sometimes migrate to the cool regions of a malt store. Except where new hot malt touched the inhabited cracks in these cool regions, the larvae were very slow to move into the malt.

In undisturbed conditions larvae have been seen walking on the walls, but only at high temperatures. A large number of larvae emerged from cracks when the temperature increased sharply after a long period at low temperatures.

Infestation at one malting has been successfully reduced by avoiding the use of one small store comprising about ten per cent. of the total storage space, which had been the chief source of infestation. Only very slight breeding has taken place elsewhere. It is expected that if this policy is continued the infestation will become negligible. (*H. D. Burges*).

Laboratory study of development and behaviour

A typical infestation includes two types of larvae, long-lived and short-lived. At a constant temperature of 30°C, both types have three or four moults alternating with feeding periods each similar to that recorded between 73 and 81 days in Fig. 1. The short-lived larvae then pupate. The long-lived larvae, on the other hand, undergo a number of extra moults and feeding periods and also one or more long resting periods during which no feeding occurs (Fig. 1).

Some short-lived larvae hide in cracks for a few days, using them only as sites for moulting or pupation. In contrast, the long-lived resting larvae hide in cracks for a long time. Even when they are disturbed daily their oxygen consumption is very low; but when they are undisturbed in the cracks the oxygen consumption falls to an exceptionally low level (Fig. 1). This great reduction in metabolism enables some larvae to survive starvation for more than 18 months at 30°C. When cracks are provided long-lived larvae spend less time in the food material, and eat less, than do larvae kept in the food with no cracks provided. Beetles produced by these free larvae are heavier than those produced by larvae in cracks, or by short-lived larvae.

The percentage of long-lived larvae present in a population depends on hereditary factors as well as on the degree of crowding, but inbreeding for four generations has not revealed any simple genetical relationship.

A proportion of the larvae can be induced to come out of cracks either by providing new food or by raising the temperature. Some of these larvae pupate. The provision of new food is less effective than increasing the temperature from

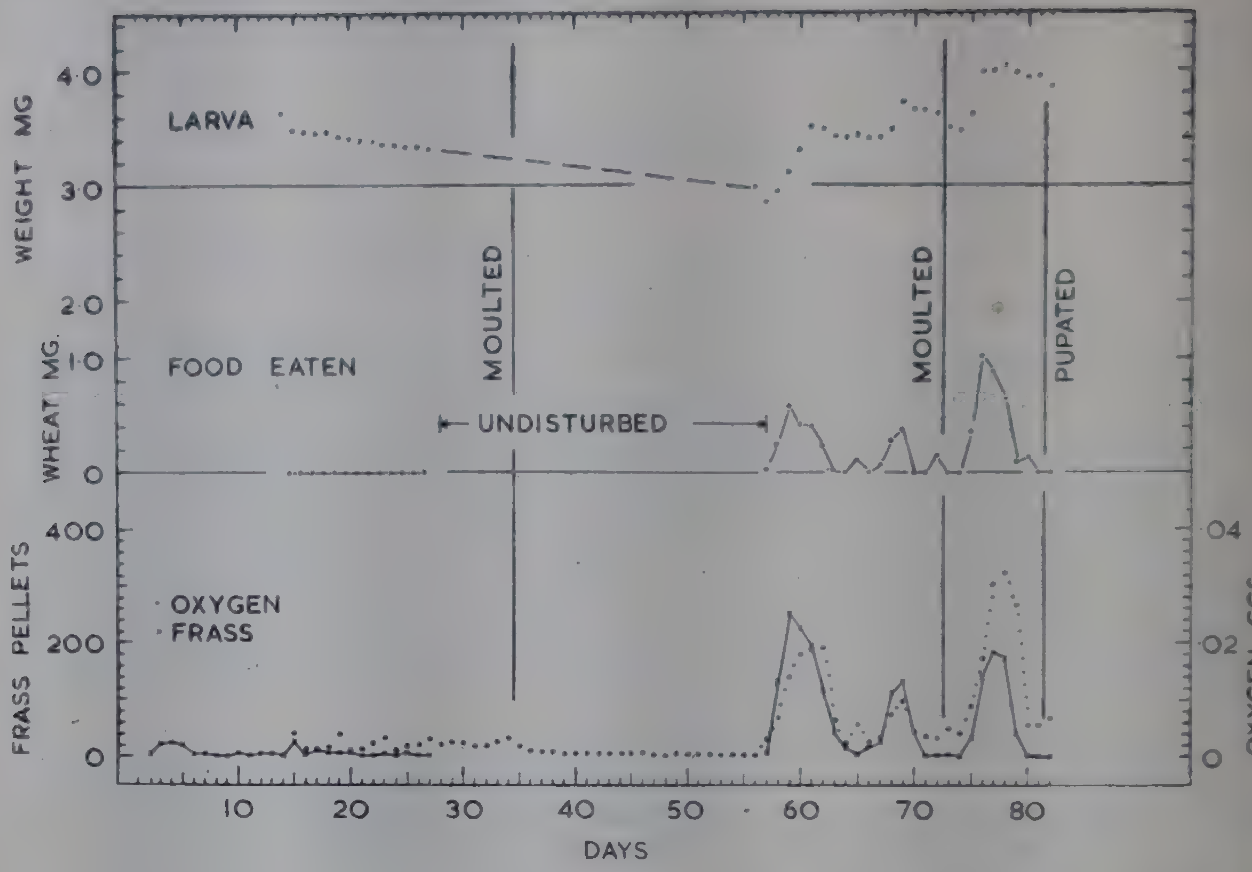


FIG. 1.—*Feeding cycle of a typical long-lived larva of* Trogoderma granarium, *when a crack is available.*

30° to 35° C or more, or decreasing it to 20° C with a subsequent return to 30°C. Even at high temperatures many larvae return to the cracks, but the cycle of movement between cracks and food is much more rapid than in cooler conditions.

The vertical movement of larvae in wheat has been studied in a limited number of experiments in metal towers 4 feet long and 4 inches in diameter. In the course of one week, large larvae placed near the top or the bottom did not move far, but many larvae placed near the middle moved to the ends. It is hoped that further work will help to explain this behaviour. (*H. D. Burges*).

BIOLOGY AND BEHAVIOUR OF THE VARIED CARPET BEETLE

Reactions to light

The study of the response of the adults of *Anthrenus verbasci* to light has been continued (cf. *Pest Infestation Research*, 1951, p. 10, and 1953, p. 10).

In a preliminary experiment where adults were tested daily it was seen that the percentage of adults attracted to light rose and fell several times as age increased.

In order to clarify this result, eighty marked adults were tested daily for the first fifteen days of life. They were kept in groups so that mating could occur and normal oviposition take place. The daily percentage of females reacting negatively to light was plotted against age, giving a curve which showed that females tended to move away from light during the peak periods of oviposition. The experiment is being repeated. (*Mrs. G. M. Blake, Miss R. Borrett*).

Oviposition

A study of the oviposition of *Anthrenus verbasci* and the way in which it is affected by adult nutrition has been completed. Twenty-one to twenty-eight pairs of beetles were maintained on each of several feeding regimes and observed daily. The total output per unfed beetle was approximately 50 eggs. When beetles were fed on nectar (a mixture of equal parts of glucose, sucrose and fructose, total 18 g/100 ml), nectar plus pollen, or nectar plus albumen, the output per female was significantly increased to 57–68 eggs; when they were fed on water, water plus pollen or water plus albumen, the output was significantly decreased to 32–37 eggs. The eggs were laid in successive batches, so that the mean number of eggs per day, given by the 20 or so replicate pairs, formed peaks of oviposition about the 6th, 12th, and 17th days.

The total length of the oviposition period was roughly proportional to the length of life. Heavier females tended to lay more eggs, and the above mean figures have been corrected for this factor.

Longevity

The mean length of life of adult females, whether unfed or given water alone, water plus pollen, or water plus albumen, ranged from 22 to 26 (males, 18–21) days. When beetles were fed on nectar (composition as above), the mean length of life was increased to 55 days (males, 42 days). The addition of albumen to the nectar increased the mean length of life to 70 days (males, 58 days). The addition of pollen to the nectar caused no significant increase in the length of life of the female but raised the mean life span of the adult to 67 days. (*Mrs. G. M. Blake, Miss R. Borrett*).

SURVIVAL AND INCREASE OF TYROGLYPHOID MITES

In continuation of work on the life history of the Flour mite, *Tyroglyphus farinae*, the development of the pre-adult stages was studied at a temperature of 10°C and relative humidities of 70, 80 and 90 per cent.

Investigations on the life history of *Tyrophagus castellanii* have also been continued and experiments completed at 15° and 20°C. At both temperatures *T. castellanii*, when bred on wheat germ at 70, 80 and 90 per cent. relative humidity, developed more slowly than *T. farinae*. At 20°C *T. castellanii* laid considerably more eggs than *T. farinae* at all three humidities, a reversal of the result obtained at 15°C but this was due to the longer life of the adult of *T. castellanii* rather than to a greater rate of oviposition.

Species	Mean development period (new egg to adult) in days at 20°C		
	R.H. 90%	R.H. 80%	R.H. 70%
Tyroglyphus farinae	13·7	15·3	20·6
Glycyphagus destructor	16·9	17·4	21·1
Tyrophagus castellanii	17·2	21·9	29·2

Difficulties in culturing *Glycyphagus destructor* have led to the discovery that it breeds well on a shallow layer of dried yeast. In consequence, it has been possible to study the rate of development and reproduction of this mite at different humidities. At 20°C and relative humidities of 70, 80 and 90 per cent, it developed at a slightly slower rate than *Tyroglyphus farinae* but more quickly than *Tyrophagus castellanii* (see Table). Its egg output, however, was considerably below that of the other two species. At 90 per cent relative humidity the mean number of eggs produced per female was only 140 for *G. destructor* as against 347 for *T. farinae* and 550 for *T. castellanii*. The last two species were fed on wheat germ flakes.

The experiments with *Glycyphagus destructor* were designed partly to throw light on the conditions affecting the formation of the hypopus stage. However, very few hypopi have appeared under these conditions.

Earlier experimental work on the resistance of eggs of *Tyroglyphus farinae* to low humidity has been extended during the year.

A few experiments at 10°C have been added to the earlier series on fumigation with methyl bromide. Some specimens of the dormant and very resistant hypopus stage of *Glycyphagus destructor* still survived after exposure to a concentration-time product of 646 mg h per litre. (*A. M. Cunnington*, *Miss M. Jackson, S. G. Heuser*).

MITE POPULATIONS ON CHEESE

Store populations

Earlier data accumulated in New Zealand and the United Kingdom concerned the mite species involved in infestations on cheese during storage, the physical conditions under which they occur, and their control through storage practice. Similar information has now been obtained from the Netherlands, where a survey was recently made. Much less mite infestation was seen on Dutch cheese than is normally found on cheese in store in either New Zealand or the United Kingdom. The same pest species are present in the Netherlands, and temperatures and humidities are even more favourable for their increase. The negligible amount of infestation, however, appears to be the direct result of store treatment. In particular, regular oiling and brushing of the cheese surface during storage makes mite build-up impossible, while mechanical scrubbing and waxing give increased protection during transport. The Dutch use dried pigs' bladders for the protection of cheese being exported to the tropics. The bladders are soaked, applied to the cheese, trimmed, and dried out again to form a complete seal over the surface. This is probably the most efficient method at present in commercial use for the protection of cheese against mites, but as it requires costly and tedious manual work, its scope is limited. (*Miss P. L. Robertson*).

Laboratory populations

The study of variation in *Tyrophagus*, one of the most important genera of mites infesting cheese, has been continued. The range of morphological variation in laboratory populations was compared with that exhibited in a field-collected series from the United States, obtained through Dr. E. W. Baker, U.S. National Museum, Washington.

The identity of the species of *Tyrophagus* studied in the laboratory was established after examination of the material in the Oudemans' Collection at the Natural History Museum, Leyden.

The systematic study of *Tyrophagus* is now being brought to a conclusion and is being written up for publication, while an ecological investigation of species involved in the cheese complex is being further developed in the laboratory. (*Miss P. L. Robertson*).

LIFE HISTORY OF *Cheyletus eruditus*

The predatory mite *Cheyletus eruditus* is common in food stores, where it attacks other mites and the larvae of insects. In granaries it has often been observed to reduce populations of *Tyroglyphus farinae*. In continuation of earlier studies of the interaction between *Cheyletus* and *Tyroglyphus*, the predator is being reared in the laboratory to find its rate of increase and its rate of consumption of prey at different temperatures and humidities. (*M. E. Solomon, Miss R. Borrett*).

LIFE HISTORIES AND PHYSICAL LIMITS OF VARIOUS BEETLES

Studies begun previously on the rate of development, mortality and reproduction under various conditions have now been completed for the following species:—

the Cigarette beetle, *Lasioderma serricorne*,
the Rust-Red Flour beetle, *Tribolium castaneum*,
the Saw-toothed Grain beetle, *Oryzaephilus surinamensis*,
the Merchant Grain beetle, *Oryzaephilus mercator* (cf. Fig. 2).

Similar studies have been continued, but not yet finished, on some of the lesser-known Spider beetles associated with stored products, namely *Ptinus sexpunctatus*, *P. hirtellus*, *P. pusillus*, *Eurostus hilleri*, and *Tipnus unicolor*.

Work along the same lines has been started with a view to making a comparative study of the life histories of the following species of *Laemophloeus*:—

L. ferrugineus (the Rust-Red Grain beetle);
L. minutus (the Flat Grain beetle);
L. turcicus, well known as a pest of flour in mills and stores;
L. pusilloides, a recently described pest of cereals, coming apparently from Australia, S. Africa and S. America;
L. spartii, an outdoor species in Britain and Europe, found in mills of all kinds;
a sixth species, not yet named, found in Uganda and W. Africa on maize and groundnuts. (*R. W. Howe, Miss J. E. Currie, Miss S. M. Nightingale*).

BIOLOGICAL OBSERVATIONS ON *Ptinus latro*

Attention was drawn to this species of Spider beetle by the inability of specialists in the group to distinguish the male from the male of *P. hirtellus*. Its irregular occurrence in warehouses, and the very small numbers usually found, have made it difficult to obtain an adequate supply of living material, and no permanent culture has so far been established. A few live examples were received from Inspectors of the Ministry of Agriculture and Fisheries, Infestation Control Division, and preliminary observations suggest that its life-history may show interesting and unusual features. (*G. E. Woodroffe, B. P. Moore*).

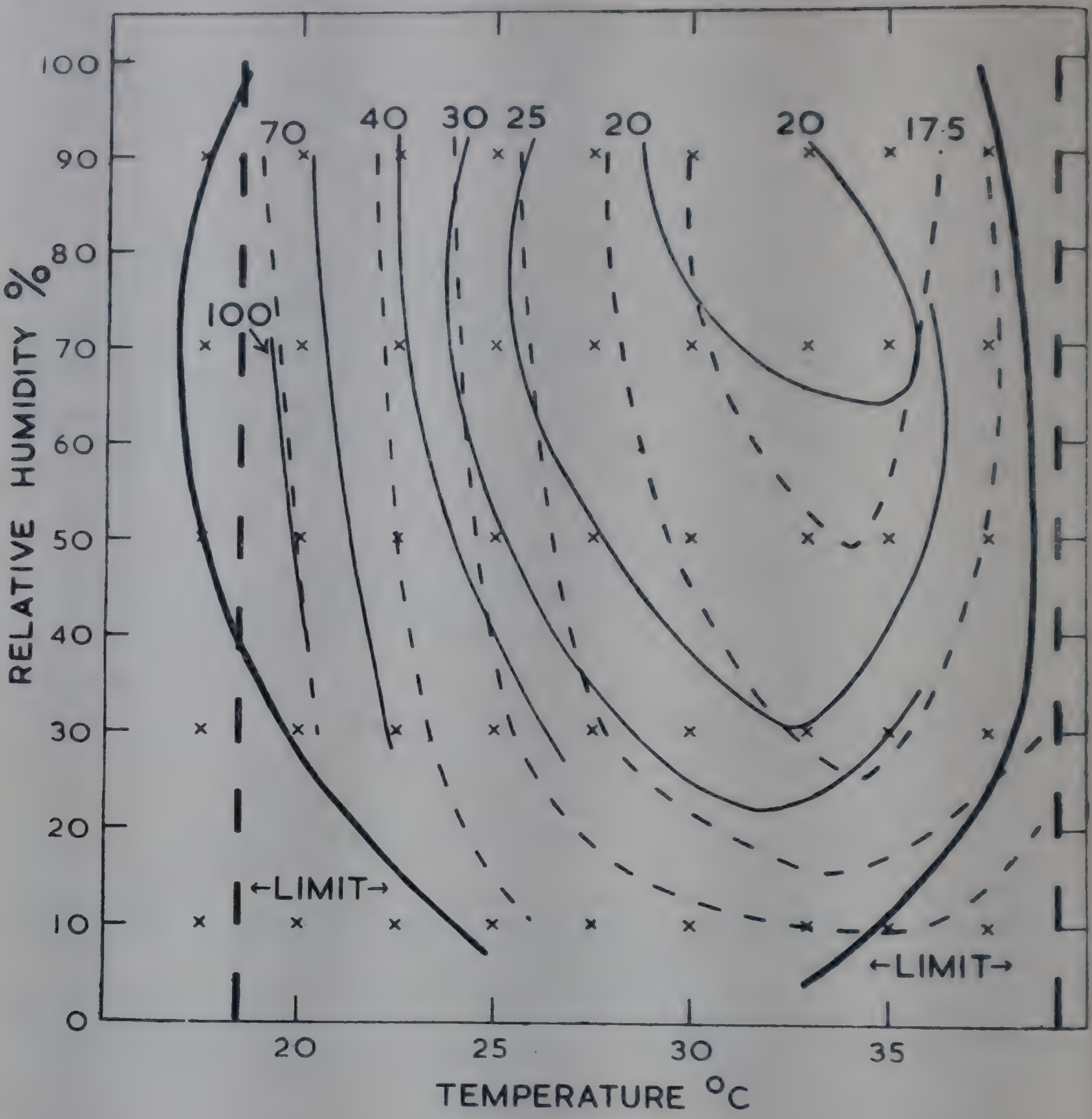


FIG. 2.—*Physical limits (thick lines) beyond which the two species of* Oryzaephilus *cannot complete their development.*

The continuous line is for O. surinamensis, *the broken line for* O. mercator. *The series of thinner lines show, for each species, the times in days for development from egg to adult. These are based on the results from experiments at the combinations of temperature and humidity marked by the crosses. The food material was wheat feed middlings.*

TAXONOMY OF VARIOUS INSECTS

The study of the British species of *Cryptophagus* has now been concluded and a paper prepared for publication. This includes a new key to the British species and over 120 figures. Identifications are still being carried out for the Infestation Control Division of the Ministry of Agriculture and Fisheries, and one beetle which they collected alive on oats from Vancouver, proved to be *Salebius tarsalis.* The genus is confined to the West coast of N. America and none of the five species have been recorded since their original description in 1900. An account of this insect has been published. The work on *Cryptophagus* has now been extended to cover American species and a large collection from the

Californian Academy of Sciences, San Francisco, is being studied. Already a number of European species have been recognized and many cases of synonomy are expected to arise as the work progresses. (*G. E. Woodroffe, C. W. Coombs*).

A species of *Laemophloeus* found on maize and groundnuts in Uganda and W. Africa is being described and named as new. (*R. W. Howe*).

Living specimens of *Trogoderma afrum* Preisner, recently described from Egypt, have been compared with *Trogoderma granarium*, the Khapra beetle. Besides a very close morphological similarity, the two forms have been found to interbreed. It is therefore considered that *T. afrum* is a synonym of *T. granarium* (*R. W. Howe, H. D. Burges*).

A study of a few Bruchidae (Bean weevils) is being made to facilitate identification of the species. (*B. J. Southgate, R. W. Howe*).

GRAIN STORAGE AND MYCOLOGY

During Mr. Oxley's visit to U.S.A. several discussions were held on airtight storage of grain although at present this is practised in U.S.A. only for damp corn used as animal feed. The most important development in grain storage in recent years in U.S.A. has been the use of low volume, cold air, ventilation in autumn in order to keep the cooling of grain in step with the climate and thus prevent local damage due to convection and translocation of moisture.

HERMETIC STORAGE OF GRAIN

The experiments on the hermetic storage of grain have continued. One of the two 10-ton bins which were filled with Atle wheat at a moisture content of 23 per cent in August 1953 was opened in April 1954; the second one was still sealed at the end of the year.

Apart from slight compaction just above the bottom slide, the grain ran freely from the bin. It was not caked and showed no visible mould growth and no moulds or yeasts could be detected in the laboratory. It was in fact, very bright in colour and had an attractive appearance. The moisture content was the same as at the time of sealing and as expected, the germination was zero. The grain had a pronounced " fruity ", or " sour-sweet ", smell which was not completely removed during the subsequent drying. It also had a strong and unpleasant flavour. The taint persisted slightly through the milling and baking processes which were carried out on small samples by the Cereals Research Station of the Research Association of British Flour-Millers. Although the volume, texture and flavour of " pup " loaves without improver were only slightly different from those from a non-airtight dry grain control, the addition of potassium bromate (which is used commercially as an improver) greatly increased the difference and showed that the properties of the dough and the baking quality of the flour had been appreciably damaged. The grain must therefore be regarded as ruined for commercial flour production. There is thus no doubt that 23 per cent. moisture content is too high for successful prolonged hermetic storage of grain at the temperatures which prevailed in Slough in 1953–54.

The main permanent effect on the grain, apart from loss of viability, was the persistent sour-sweet smell and unpleasant flavour. It is assumed that this is

largely due to the appreciable anaerobic respiration of micro-organisms made possible by the high moisture content. Small scale tests showed that the taint was noticeably reduced by sealing the grain in an atmosphere of carbon dioxide from the start.

The 1954–55 tests in the 10-ton bins were planned to use drier grain than the previous year, and with carbon dioxide passed into one of the bins during filling so that the grain was surrounded by a high concentration of carbon dioxide when the bin was sealed. It was also planned to clean the grain on a simple winnowing machine. Owing to the exceptionally bad harvest conditions great difficulty was experienced in combining the wheat at all, and although the bin charged with carbon dioxide was successfully filled with grain at the moisture content planned (18–19 per cent), the " control " bin without carbon dioxide had grain much damper than this (22·8 per cent). It is too early yet to report results of this test except to say that the rate of build-up of carbon dioxide in the bin containing the damper grain has been appreciably slower than in 1953–54, presumably due to the lower temperature of the grain at harvest and to more efficient cleaning of the grain, which removed much green leafy material.

Behaviour of damp grain after removal from hermetic conditions

Most of the ten tons of grain removed from the bin which was opened in April 1954 was dried and sold. Thirty sacks were retained, however, and built into a small stack in an unheated wooden building. Temperature records by thermocouples at various points in the stack showed that there was no appreciable rise in temperature from the initial value of about 9°C for about six weeks during which time ambient temperatures varied about the same mean temperature. After this the grain began to heat rapidly, a change which appeared to have been initiated by a brief spell of warmer weather. Patches of mould then began to develop. These were distributed through the sacks, which suggests that they arose from surviving micro-organisms rather than by invasion from outside. The relatively small number of patches of mould showed that the survivors were scanty and probably unmeasurable by mould count.

The conclusion from this small experiment on stacking is that damp grain removed from hermetic storage in the cool days of spring remains cool and free from mould for some time. It may therefore be less unwise than at first thought to open a hermetic bin, and remove only part of its contents. It is therefore planned to do an experiment during 1954–55 in which a bin will be opened at intervals, and some grain removed. The subsequent behaviour both of the grain remaining in the bin and of that which is removed will be studied. (*T. A. Oxley, Miss M. B. Hyde, G. Ayerst, Miss G. Wickenden, Miss M. Keeping*).

INSECTICIDES

The loss of one trained member of the staff and his replacement four months later by an untrained member has resulted in a reduction in the work on some of the more *ad hoc* problems.

No major change in the programme of work of the Insecticide Section has taken place during the year, all the main investigations having been continued from last year. Certain investigations, viz.: bio-assay of pyrethrins using the loss in weight of Flour beetles, the development of an improved model of the

micro-drop applicator, the control of Bean weevils with insecticidal dusts, a new method for chemical assay of pyrethrins, and control of DDT-resistant flies on rubbish tips, have now been terminated and papers on some have been prepared for publication.

About 190 enquiries have been answered with occasional visits for inspection, or experimental treatment if the circumstances were of special interest. A third advisory note has been prepared and duplicated to aid in answering enquiries on the Fur beetle in houses. Help has also been given to the Colonial Liaison Officer in preparing suggestions or recommendations for treatment of various commodities in store overseas. In the course of correspondence a summary of all the knowledge and experience of the Biology, Insecticide, and Fumigant Sections relative to the habits and control of the Khapra beetle has been made available to entomologists in California, where infestations by this insect have been discovered.

The Section provided an exhibit on the control of blowflies at the Health Exhibition organized by the Metropolitan Borough of Islington (Plate (IA)).

Discussions have continued with the Ministry of Works on the plans for the new building to house the Section but the start of the building work has been delayed.

PERMEABILITY OF SACKING TO INSECTS

Experiments are in progress, in collaboration with the British Jute Trade Research Association, to determine the period for which sacking impregnated with pyrethrins and piperonyl butoxide prevents the passage of insects when the sacking is stored in the light.

Samples of crepe paper stuck to jute sacking with a bituminous adhesive were supplied by the British Jute Trade Research Association to test whether insects could penetrate through it. Insects were confined on the sacking, and suitable foodstuff was kept on the opposite side of the material, in contact with the adherent paper. Flour beetles, *Tribolium castaneum*, Cigarette beetles, *Lasioderma serricorne*, and larvae of the Cacao moth, *Ephestia elutella*, failed to pass through to the foodstuff, but Granary weevils, *Calandra granaria*, did so, though apparently with difficulty. All these test insects readily passed through unlined sacking. Only Cigarette beetles penetrated through crepe paper alone (i.e. not stuck to sacking): possibly Granary weevils failed to do so because they were unable to gain sufficient foothold for biting holes. (*K. G. Gostick*).

On behalf of the War Office three types of multi-ply paper sacks, incorporating a polythene or bitumen layer for moisture proofing, are under test to ascertain whether they will protect stored flour against insect infestation. A pair of each type, filled with flour, is being exposed to numbers of the Flour beetle, *Tribolium castaneum*, in a special cage under conditions of relatively high temperature and relative humidity. So far only a preliminary examination of one of each type of sack has been made, but it appears that a very low level of infestation has occurred through the stitched ends. (*E. A. Parkin, C. J. Lloyd*).

MECHANICAL PROTECTION OF GOODS BY SHEETING

When clean goods have to be kept in an infested store it is usually very difficult to protect them satisfactorily against cross-infestation. It was thought that this

protection should be achieved if the goods could be covered by a closely woven sheet, provided that the sheet could be so fixed at the foot of the pile that insects would be unable to crawl under it. To test this possibility a small experiment was set up in which four piles of 100 lb of wheat were put on the floor of a room and separated by sticky bands. (Plate I (B)). One pile was left untreated; a second was surrounded by a ring of DDT powder; a third was covered with muslin lightly weighted at the edge beyond the perimeter of the grain; the fourth had a muslin cover the edge of which was weighted on to a ring of DDT powder. Granary weevils and Flour beetles were released round the foot of each pile. The degree of protection offered by the muslin was slight, by the DDT ring considerable, and by the combination of muslin and DDT ring nearly complete. Improvements in the method could easily be made to ensure complete protection under laboratory conditions. An experiment to test the protection given to grain in a dustbin (simulating a silo bin) by a muslin cover sealed to the wall by a narrow band of DDT dust gave equally encouraging results. These simple tests seem to have established the principle of the method sufficiently to encourage those who might use it in practice to put it to trial so that ideas for the joining of multiple sheets etc. can be tried. (*E. A. Parkin, G. T. Bills*).

CONTROL OF BEAN WEEVILS

It was reported last year that laboratory tests had shown that the Bean weevils, *Acanthoscelides obtectus* and *Callosobruchus chinensis*, could be prevented from infesting peas and beans by mixing 6 oz of a diatomite powder incorporating 0·05 per cent gamma-BHC into each 200-lb bag. Additional tests have now shown that similar results could be achieved with 0·05 per cent gamma-BHC on a kaolin base. The diatomite base is preferable, where obtainable, because it itself posseses slight protective properties. Other dust treatments effective at a dosage of 6–8 oz per 200 lb of the commodity were a finely divided colloidal silica and a colloidal aluminium pentasilicate (both commercially available), finely ground diatomite, and 0·5 per cent technical DDT on diatomite or kaolin. Ground rock phosphate, kaolin, or talc were not effective at the dosages tried. Gamma-BHC and DDT used at the above rates would be present in the product at only 1 and 7 p.p.m. respectively and it is therefore unlikely that the commodity would be tainted or rendered toxic to man or animals, even if no cleaning were undertaken.

A full account of this investigation has been prepared and submitted for publication. (*E. A. Parkin, G. T. Bills*).

CONTROL OF GROUNDNUT WEEVILS

Because of the importance of the groundnut weevil, *Caryedon fuscus*, as a pest of undecorticated groundnuts a preliminary test has been made in small jars in the laboratory to find whether this species is susceptible to the same insecticides as are mentioned above for control of its close relatives, the Bean weevils. At 30°C and 70 per cent R.H., finely divided colloidal silica and colloidal aluminium pentasilicate were effective at the rather high dose of 0·5 per cent by weight, whereas kaolin failed to afford protection at 0·75 per cent; and DDT did not protect the groundnuts when admixed at the rate of 28 p.p.m. or less. whereas gamma-BHC gave good protection at 1·0 p.p.m. or more. (*E. A. Parkin, G. T. Bills*).

THE EFFECT OF INSECTICIDES ON THE CACAO MOTH

A few tests have been made of the susceptibility of the various stages of the Cacao moth, *Ephestia elutella*, to different insecticides but progress has been interrupted by a change in staff. The results so far obtained must be regarded as tentative. The moths seemed more content to rest on bricks treated with a BHC wettable powder than on those treated with DDT, although they showed toxic symptoms much more quickly on the former. The vapour of gamma-BHC was more toxic to all stages of the insect than the vapour of dieldrin. Eggs continuously exposed to the vapour of gamma-BHC developed until ready to hatch and the larvae died in the act of hatching. Larvae 3-weeks old soon died but many fully grown larvae exposed for 3 days succeeded later in pupating; few adults emerged and they soon died. Pupae exposed for 3 days appeared to continue their development normally but the emergent adults showed toxic symptoms and died. (*G. T. Bills*).

PERSISTENCE OF PYRETHRUM FILMS ON COATINGS OF UREA-FORMALDEHYDE RESINS

Coatings of urea-formaldehyde resins containing insecticides, deposited on walls, etc., are coming into use for control of domestic insects and, to a lesser extent, of stored product insects. The coatings eventually lose the toxic properties derived from the insecticide originally incorporated, and it is possible that pyrethrum in oil may then be sprayed on. The persistence of films formed by pyrethrum in Shell Risella oil 17 on resin coatings, without insecticide incorporated, has therefore been tested. Resin coatings on wood and concrete supported pyrethrum films only slightly longer than did the uncoated substrate. In this respect the resin was much inferior to gelatin, a coating of which has been shown (Hewlett & Parkin, 1947) to support highly toxic pyrethrum films for considerable periods. (*K. G. Gostick*).

BIO-ASSAY OF PYRETHRINS

The development of a method for bio-assay of pyrethrins by weight loss from flour beetles, *Tribolium castaneum*, is now complete and a description has been submitted for publication. Physiological investigations have indicated that the weight loss of pyrethrin-treated beetles is principally a loss of water vapour through the spiracles. When beetles were exposed to pyrethrins, as in the bio-assay method, their rate of oxygen uptake rose rapidly and then fell more slowly. During the rapid rise the weight loss could be accounted for on the assumption that it is a secondary effect of increased respiration. However, as the rate of oxygen uptake decreased the rate of weight loss for a time remained nearly constant, suggesting that some other factor supervenes, such as, perhaps, spiracular paralysis. (*P. S. Hewlett, K. G. Gostick*.)

CHEMICAL ASSAY OF PYRETHRUM

Work has continued on the 2: 4-dinitrophenylhydrazine method for pyrethrum assay and an improved photometric version has been derived. Tests on a series of pyrethrum and allethrin standards and concentrates indicated that the new method was consistent, accurate, and applicable to both types of insecticide.

The standard mercury-reduction method has also been tested and has given seriously high results, the margin of error ranging from about 10 per cent on

pure materials to 50 per cent or more on crude oleo-resins. These errors result largely from the effect on the final value of considerable quantities of non-insecticidal ' polypyrethrins ' together with smaller amounts of other extraneous materials.

An account of this work has been published. (*B. P. Moore*).

RELATIVE SUSCEPTIBILITY OF INSECTS TO INSECTICIDES

Considerable progress has been made with the investigation, started last year, into the relative susceptibility to pyrethrins of a wide range of stored product insects. It is intended to group the species and stages according to their susceptibility to 1·3 per cent pyrethrins, 0·3 per cent pyrethrins + 3 per cent piperonyl butoxide, and the base oil alone. The insects are treated either by direct spraying or by confinement on sprayed filter papers. The details of the technique have frequently had to be modified according to the species and stage used.

The range of susceptibility so far encountered is very wide. The Granary weevil, *Calandra granaria*, was previously known to be susceptible to the oil alone; the other insects tested have proved much more resistant. With the two kinds of pyrethrum preparations, the relative resistance of some species and stages varies considerably according to the method of application and generally to a much less extent according to the preparation. The possibility of subdivision of the insects tested into broad categories of relative resistance is now being realized but still more data are needed before attempting to relate resistance to systematic position, etc. (*C. J. Lloyd*).

VALONE FORMULATIONS

In further work on the synergism of valone (2-*iso*valeryl 1, 3-indandione) by gamma-BHC in killing the larvae of the Khapra beetle, *Trogoderma granarium*, the synergistic effect has been found to be much more pronounced for dusts than for solutions in light oil (odourless kerosine). For dusts, synergism occurred over a wide range of proportions of the two insecticides. The larvae (Woolly bears) of another Dermestid (the Carpet beetle, *Anthrenus verbasci*) are like the Khapra beetle larvae in being highly resistant to the contact insecticides in common use, and very slow to die after receiving a lethal dose. Gamma-BHC was found to synergize the action of valone on Woolly bears also, and under laboratory conditions a dust containing the two substances proved both highly toxic and quickly lethal to the larvae. Unfortunately the mammalian toxicity of valone precludes its widespread use in households, etc., but chemical and biological investigations are proceeding to find if related compounds offer more promise (see below). (*P. S. Hewlett, Mrs. P. J. Maycock, Miss D. G. Blackman, Miss C. Belcher*).

SYNTHESIS OF CONTACT INSECTICIDES

Valone (2-*iso*valeryl-1 : 3-indandione) and related compounds have unusual insecticidal properties (see Report for 1953, p. 19) which appear to be associated with the β-triketone group. It would be of interest to determine the optimum molecular requirements for this activity and the synthesis of a number of model compounds has been undertaken with this end in view. The work has not yet progressed sufficiently for an assessment to be made but there are indications that a ring-keto structure is essential (*B. P. Moore*).

METHODS FOR TOPICAL APPLICATION OF INSECTICIDES

A simple method, which appears very satisfactory, has been developed for topical application to insects of mobile liquids, including solutions of insecticides in volatile solvents. With such solutions micro-syringes sometimes give deliveries containing excessive solute. However, the principle of the self-filling capillary pipette has been successfully used, but short lengths of fine glass capillary in suitable holders have given sufficient reproducibility, i.e. the constricted tip of the normal type of micro-pipette is here unnecessary. Individual deliveries from capillaries have been measured radiometrically by the Biochemistry Section. The coefficients of variation for deliveries of an acetone solution of ^{32}P labelled phosphate were 4·6 and 6·5 per cent for capillaries giving mean deliveries of 0·25 and 0·03 μl respectively.

A low-power (4: 1) micro-manipulator has been designed and built for positioning insects when firing single drops of insecticide on to them by means of the improved air-pulse micro-drop applicator (Plate II (A)). The manipulator replaces a screw-adjusted table used previously, and considerably speeds the treatment of the insects.

Air-pulse micro-drop applicators are suitable for topical dosage of relatively non-volatile, mobile or viscous liquids, and the micro-capillaries for that of mobile liquids. Since volatile liquids are mobile, a wide variety of liquids covering a very wide range of physical properties can now be applied topically. Mobile, relatively non-volatile liquids such as odourless kerosine can be applied by either type of apparatus. (*P. S. Hewlett, M. A. Cordaroy*).

FUNDAMENTAL STUDIES WITH SOLUTIONS OF INSECTICIDES IN HEAVY OIL.

A fundamental study is in progress on the action of solutions of insecticides in Shell Risella oil 17 which are being applied topically to Black Fungus beetles, *Alphitobius laevigatus*. It is providing information that will permit proper interpretation of experiments involving topical application as well as, it is hoped, of some of the effects on stored product beetles of the different types of dosage they receive under practical conditions.

The insecticides to be used were required to exert a contact action only, to be chemically stable and, so far as possible, chemically homogeneous. Those selected were p,p -DDT, dieldrin, 2-*n*-valeryl 1,3-indandione, and allethrin (mixed isomers—the (±)-*trans* isomer was insufficiently soluble). Though all four are probably nerve poisons, they show wide differences in their speeds of action and in the symptoms of poisoning they produce. Drops of closely controlled volume within a range of 0·02–0·08 μl are fired on to selected parts of the beetles by means of the air-pulse type of applicator. A considerable amount of preliminary investigation has been necessary to ensure sufficient control of the experimental conditions.

The main investigation is to determine (1) the relation between mortality (or a near equivalent) and the dose when applied to a selected part of the beetle's body, (2) the dependence of toxicity on the part treated, and (3) how the toxic effects of one insecticide applied simultaneoulsy on different parts are summed. Under (1) it was found that probit mortality could be represented by a plane in log-concentration and log-volume: for each of the insecticides DDT and allethrin the coefficients for regression on the two variables were unequal, which implies that the toxic effect of these two insecticides is influenced by the

quantity of oil in which they are dissolved. Under (2) it was found that application of an insecticide to certain sites on the beetle gave parallel probit planes: this probably applies to all sites. Thus the relative effectiveness of an insecticide on different sites appears to be independent of dose level. The toxicities of the three insecticides other than dieldrin definitely depended on the site of application, but the differences were not large, the most " sensitive " site of application being roughly 1·4 times as sensitive as the least. Dieldrin was exceptional in that the site of application made no appreciable difference to its toxicity. The results under (3) are as yet incomplete.

The initial localization of the early paralytic effect of allethrin was striking. When a drop was applied between a pair of coxae (whence it was drawn into the coxal cavities), or near the bases of the antennae, the pair of appendages nearest to the site of application were paralyzed considerably before the others. (*P. S. Hewlett, Miss C. Belcher*).

CONTROL OF CACAO MOTH IN WAREHOUSES

Toxicity tests

Recommendations for control of the Cacao moth, *Ephestia elutella*, based on the 1953 experiments, were adopted by the Infestation Control Division, Ministry of Agriculture and Fisheries, and incorporated in memoranda to inspectors.

The experiments have been extended during 1954 in order to find more economical and less laborious methods of control. The same London warehouse was utilized but nine stowages were chosen in which no insecticide having residual toxicity had previously been used. The following treatments were given:

(1) A repeat of the 1953 treatment using a portable electric machine to apply, from a distance of 3 to 10 feet, a mixture of 0·3 per cent pyrethrins and 3 per cent piperonyl butoxide in heavy oil at the weekly rate of 2 pints per 2500 sq. ft. of bag surface.

(2) An equivalent dose applied monthly (1 gal per 2500 sq. ft. per month).

(3) A repeat of (1) at $\frac{1}{4}$ dosage rate ($\frac{1}{2}$ pint per 2500 sq. ft. per week).

(4) A repeat of (2) at $\frac{1}{4}$ dosage rate (2 pints per 2500 sq. ft per month).

(5) An equivalent dose to (1) but applied fortnightly as a space fog by fixed, unattended machines.

(6) DDT insecticidal smoke applied fortnightly at the maximum rate recommended by the manufacturers.

(7) Lindane smoke applied as for (6).

(8) and (9) Controls not treated.

Weekly estimates of numbers of moths were made. All spray treatments and the lindane smoke kept moth populations at a very low level, but the DDT smoke, although killing moths at the time of application, seemed to have little residual effect and allowed a build-up of population between treatments.

Both smoke treatments gave a dense, acrid smoke in which it was impossible to work and which caused considerable dislocation of work in adjoining stowages. It is unlikely that such treatments could be used in practice except in isolated stowages where no work is in progress.

The method of measuring the degree of control of consequent larval infestations was similar to that used in the previous year but in each stowage were stored ten small bags each containing about 14 lb of cacao beans or cacao waste instead of the four 1 cwt sacks. The bags were again brought back to the Laboratory and the larvae migrating from them trapped and counted.

The migration of larvae is not yet complete but so far it appears that excellent control has been achieved in all the sprayed stowages and it seems likely that existing methods can be modified so as to effect greater ease of application and an economy in time and materials. Lindane smoke has also apparently achieved excellent control and DDT smoke moderately good control despite the apparently low toxicity to adult moths. For reasons already stated however, neither of these treatments is likely to be generally adopted. (*A. A. Green, G. T. Bills, Miss M. J. Kane, D. G. H. Halstead*).

The measurement of spray deposits

For the purposes of accurate comparison only one type of insecticide applicator was used in the toxicity tests. Since, however, control is brought about largely by the residual insecticidal film, equally good results should be obtainable using any method which will achieve a similar range of deposits and distribution of insecticide.

A method of measuring such deposits on sacking has been evolved. Small pieces of sacking are conditioned at 20°C and 70 per cent R.H., weighed, exposed at various parts of a stowage during spraying operations, conditioned again and re-weighed. Deposits obtained during the previously described toxicity tests have been determined and comparisons made with those obtained by using other appliances. Various factors affecting deposition of spray, such as particle size of droplets and the movement of air, are being studied. It seems likely that similar results can be obtained by several methods and that the final selection of apparatus will depend largely on cost, ease of operation and availability.

It has been found that, when spraying for residual deposits all doors and windows can be opened immediately spraying ceases since, for all practical purposes, the deposition of insecticide is complete. The amount of dislocation of normal work is, therefore, reduced to a minimum. (*A. A. Green, Mrs. P. J. Maycock, G. T. Bills*).

VARIATION IN INSECT RESISTANCE

In this long term work, testing the standard stock of the Confused Flour beetle, *Tribolium confusum*, has continued, using methyl formate as the insecticide. No appreciable change in level or range of resistance has occurred, indicating that the resistance has been successfully maintained at the stable level, although the homogeneity of the data was not quite so good as last year.

The effect of various humidities during the fumigation procedure has been investigated and no significant differences found among the mortalities of beetles over a range of relative humidities from 40 to 76 per cent. The effect of gas flow through the insect containers on final mortality has been retested. Comparison of flow rates of 5·5 litres/min and 0·25 litres/min showed no significant difference in their effects.

A "pearl-eyed" mutant appeared some time ago in the standard stock. It has, however, been found similar in resistance to the standard beetles and has therefore been left in the stock.

Cultures from the standard stock have been made at 30°C, in addition to those kept at 25°C, and some preliminary tests made at various combinations of 30°C and 25°C for breeding, maturing, and fumigation.

Sub-lethal treatments of two strains have continued for 13 generations in an attempt to build up resistance to methyl formate. The resistance has not risen above 1·7 times that of the standard stock. There has therefore been no gain on the results reported last year and it seems that this level of resistance is not likely to be exceeded under the present experimental conditions. (*J. A. Hope, Miss R. Phillips*).

MOTHPROOFING TESTS

The Laboratory has continued to take part in the inter-laboratory tests arranged by the Mothproofing Committee of the International Wool Trades Organization. The large-scale trial mentioned in the last Annual Report, in which repetitive testing was to be done at intervals to gain information on variation within and between laboratories over a period of time, has proceeded throughout the year. To date, seven tests have been completed using a carefully standardized technique in which special attention has been given to controlling breeding and exposure temperatures and relative humidities, culture medium, age and size of larvae, and method of handling the patterns. The results of the first three tests were submitted for collaborative statistical analysis. The conclusions from this preliminary analysis were discussed at a meeting in Brussels in June. The gain in precision of the tests was sufficiently marked to be very encouraging and certain modifications were agreed to the second half of the testing schedule. (*E. A. Parkin, Mrs. P. J. Maycock, Miss D. G. Blackman*).

Mothproofing tests have been carried out, using the Brown House moth, *Hofmannophila pseudospretella*, as the test insect. It was found necessary to increase the exposure period from two to four weeks when using this insect. Of two treated fabrics exposed, one nearly failed against 4-week old larvae, whereas the other has shown itself to be proofed against both 4-week and 8-week old *Hofmannophila* larvae. Tests have also been made with larvae of the Varied Carpet beetle, *Anthrenus verbasci*, as test insect. It was again necessary to increase the exposure period to 4 weeks. At the end of this period the insects had damaged the untreated cloth as much as larvae of *Tineola bisselliella* in 2 weeks, but had done much less damage to samples treated with mothproofing agents. A test to assess the effect of relative humidity of exposure on amount of damage, using *T. bisselliella*, showed that within the range of 55 per cent to 75 per cent R.H., humidity had no important effect. (*Mrs. P. J. Maycock, Miss D. G. Blackman*).

CONTROL OF CARPET BEETLES

The efficacy of paradichlorbenzene as a deterrent to *Anthrenus vorax* attacking Service uniforms has been tested. Uniforms were wrapped in brown kraft paper together with 1 g paradichlorbenzene crystals per 100 g uniform. The uniforms were then infested with eggs, larvae, and adults of the insect. After 8 weeks the packages were opened and the uniforms examined. All the crystals had

(A) *Fumigation of H.M.S.* Victory. *Testing the penetration of fumigant through blocks of wood containing tests insect (p. 32)*

(B) *Testing the efficiency of different treatments applied to concrete to prevent the penetration of water vapour (p. 46)*

PLATE III

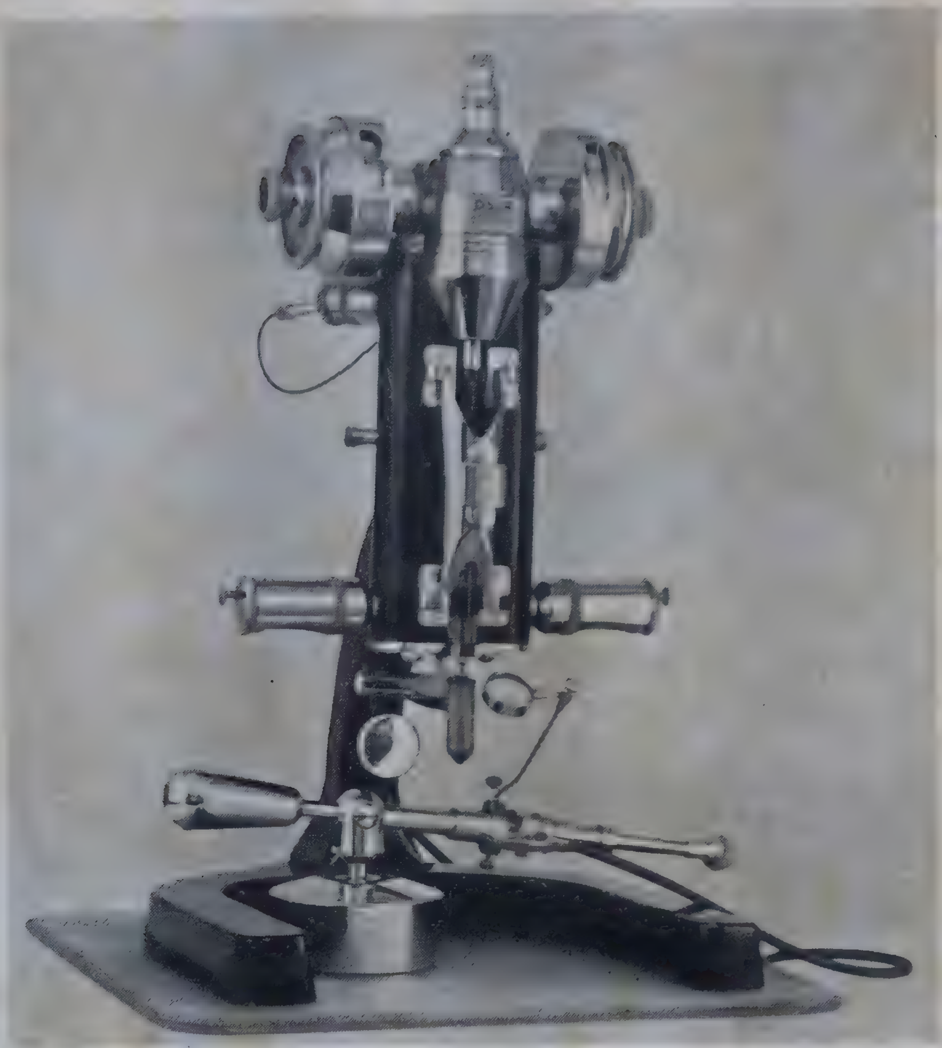
Visit of Commonwealth entomologists to the Pest Infestation Laboratory

PLATE IV

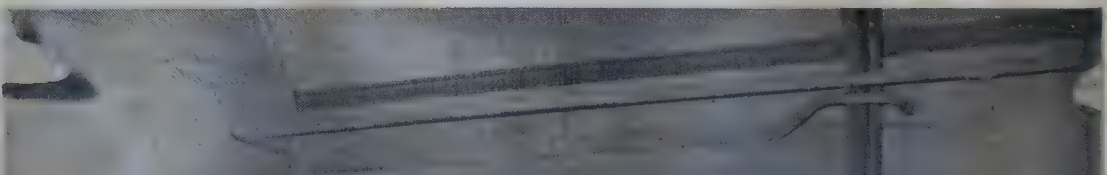
(A) *Control of blowflies. Exhibit at the Health Exhibition, Islington* (*p. 17*)

(B) *Experimental protection of grain by sheeting* (*p. 17*)

PLATE I



(A) *Improved micro-drop applicator and low-power micro-manipulator* (*p. 21*)



(B) *Control of Pharaoh's ant in a hospital. Painting bands of insecticide on walls.* (*p. 25*)

PLATE II

evaporated leaving only a very slight smell. All the adult beetles were dead and 90 per cent of the larvae; many of the eggs had hatched but all the young larvae had died. It can be concluded that, although 100 per cent control of an infestation could not be guaranteed, paradichlorbenzene could exercise a useful degree of control under these circumstances over a short period. Two experimental smoke treatments of roof spaces have been made using DDT and BHC smokes. Neither gave satisfactory control. (*Mrs. P. J. Maycock, Miss D. G. Blackman*).

Among the enquiries on Carpet beetles dealt with during the year were two which concerned the Australian Carpet beetle, *Anthrenocerus australis*. Although known to occur in wool mills in Scotland, these are the first occasions on which we have been consulted about this species in factories in England. One infestation was widespread in a factory using animal hair and wool yarn for the manufacture of haircloth and interlining. A visit of inspection showed that the insects were established not only in accumulations of waste hairs and trimmings but also in sparrows' nests in the factory roof. The second instance concerned a brush factory and was dealt with by correspondence. Both enquirers were advised to regard the infestation as serious and to undertake prompt and thorough control measures. (*E. A. Parkin, Mrs. P. J. Maycock*).

CONTROL OF PHARAOH'S ANT IN HOSPITALS

The previously reported trials using chlordane against Pharaoh's ant, *Monomorium pharaonis*, showed that single buildings could be cleared and kept free of infestation. These trials have been extended to determine whether similar treatments could be applied with equal success to a complex network of buildings.

A large tuberculosis sanatorium, where treatment of a single block was undertaken last year, was used for the experiments. It consisted of 17 wards and other buildings, each isolated geographically but with inter-communicating underground ducting which carried hot water pipes and other services (see Fig. 3). The ducting could be reached with difficulty by lifting concrete slabs, but was otherwise inaccessible.

All buildings were heavily infested with Pharaoh's ants which had established nests, not only throughout the ducting, but also in cracked walls and ceilings, behind sinks and boilers and up chimneys and flues. Some ants were living outdoors, apparently nesting in the warm earth adjoining drains carrying hot waste, but entering buildings to forage.

Previous findings were put into practice as follows:

(1) Treatments began in buildings on the periphery of the sanatorium, working in to the kitchen and power house blocks, and at the top of buildings working down to the ground floor and ducts.

(2) Insecticide, consisting of 2 per cent chlordane in refined kerosine was painted in bands, 3 inches wide, along the foot of all internal walls and around pipes, sinks, ovens, etc. (Plate II (B)).

(3) Insecticide, consisting of 5 per cent chlordane in a non-inflammable oil, was sprayed in bands, 3 to 6 inches wide, along the foot of all outside walls.

(4) A powerful sprayer was used to blow a fog of the 5 per cent chlordane solution along the ducting. Two pints of insecticide were used for each 30 feet of 3×3 ft ducting.

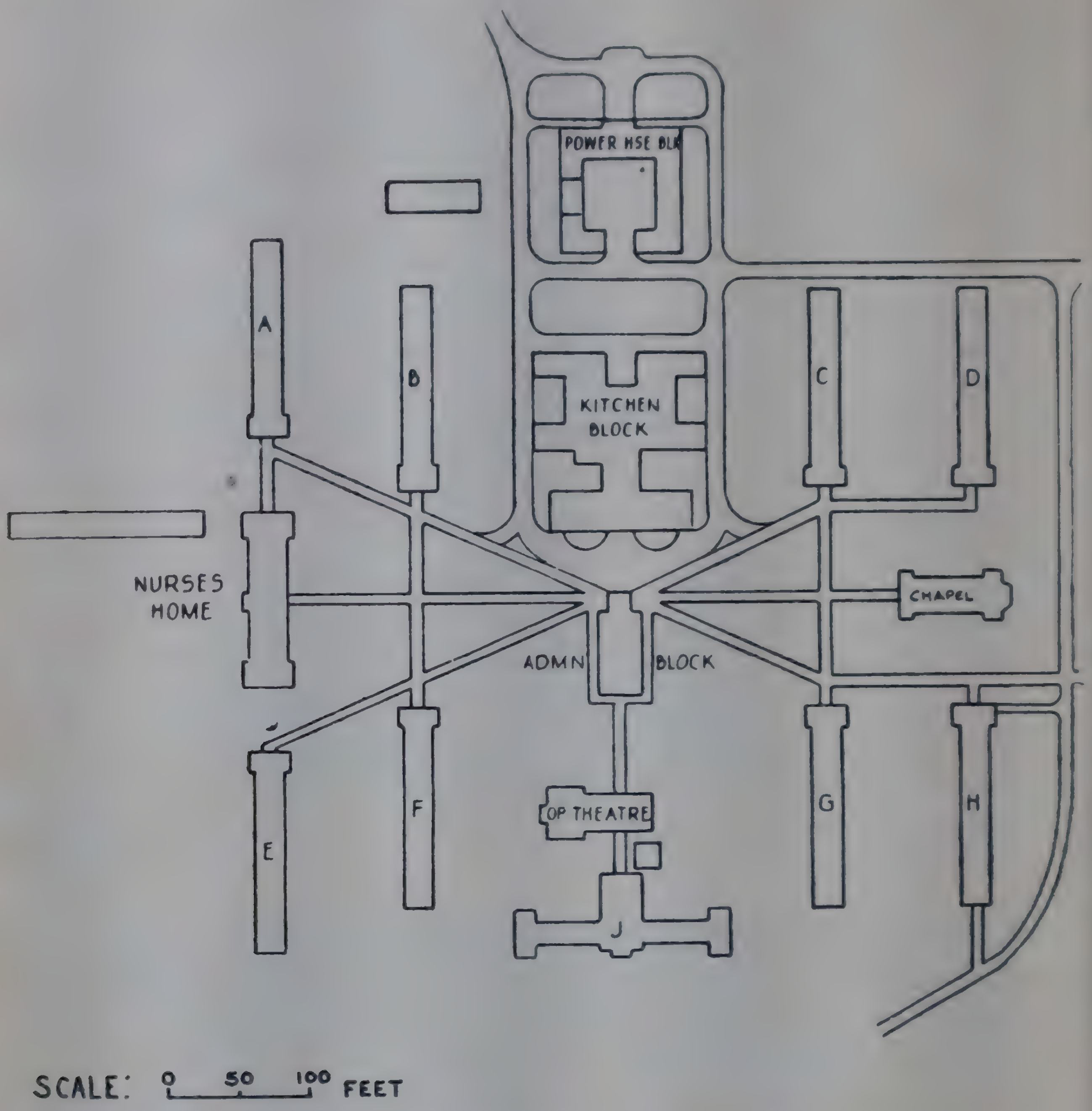


FIG. 3.—*Plan of sanatorium used for experiments on the control of Pharaoh's Ant*

This widespread treatment quickly reduced the infestation to almost negligible numbers, but there remained several nests in floors, ceilings and similar places where the ants could live without crossing insecticidal bands. These nests could be located and destroyed only by baiting, following the ants' trails, and carrying out local treatment. Every part of all buildings was baited and when necessary, treated at intervals over a period of 8 months until no insects could be detected for two consecutive baitings.

The expenditure of material and man-hours was recorded so that estimates of expenditure could be given in the course of future advisory work. The insecticide cost about £27 and labour involved 279 man-hours (172 for original treatment and 105 for inspection and retreatment). If, therefore, the hospital authorities had employed labour at, say, 3*s*. 6*d*. per hour, the cost would have been around £48 and the total expenditure, excluding capital cost of equipment, about £75.

A similar treatment was carried out at a much smaller hospital, probably about one-quarter the capacity of the sanatorium, where the infestation was comparatively light and only recently established. Here, however, the Laboratory staff acted only in an advisory and supervisory capacity and treatments were applied by officers of the local and hospital authorities. Complete control was reported after one treatment for a total cost of about £14. (*A. A. Green, Mrs. P. J. Maycock, G. T. Bills, Miss M. J. Kane*).

CONTROL OF COCKROACHES

Laboratory tests

A method has been evolved for testing insecticidal dusts against the German cockroach, *Blatella germanica*, and the Oriental cockroach, *Blatta orientalis*. The insects are released into a space encompassed by a ring of dust and, after crossing the ring, fall into a container in which they are fed and kept under observation for the next 7 days. A 2 inch wide ring of dust applied at the rate of 200 g/sq. m. (0·65 oz/sq. ft) was the most satisfactory for comparative tests.

Comparisons of 5 and 10 per cent DDT and 1 per cent lindane dusts against adult males, adult females, and nymphs of both *B. germanica* and *B. orientalis* showed that 10 per cent DDT was the most effective and that 1 per cent lindane was more effective than 5 per cent DDT. With both species, the adult males were the most susceptible to all dusts but with *B. germanica* the nymphs were the most resistant and with *B. orientalis* the adult females were the most resistant. (*A. A. Green, A. M. Simmonds, D. G. H. Halstead*).

Field Tests

A field experiment has been conducted in a pharmaceutical factory infested with the German cockroach, *Blatella germanica*. Bands of insecticide, consisting of 5 per cent chlordane in refined kerosine, were painted round the cupboards, ovens, sinks, and the foot of all walls. The infestation was completely controlled and no cockroaches were seen after 4 weeks.

An interesting effect of the treatment was that very few dead or affected insects were found. Similar observations were made at the tuberculosis sanatorium where an incidental control was achieved of the Oriental cockroach, *Blatta orientalis*, when chlordane was used against Pharaoh's ant. If, as seems likely, the insects crawl to their hiding places to die after contacting chlordane films, it would be a great advantage in public institutions where it is undesirable to have numbers of dead and dying insects on the floor, as is usual after DDT and pyrethrum treatments. (*A. A. Green, A. M. Simmonds, G. T. Bills, Miss M. J. Kane*).

FUMIGANTS

Some temporary easing of the accommodation difficulties which had become acute has been possible during the year. Three small laboratories vacated by the Biochemistry Section have been taken over, one as a laboratory for infra red spectroscopy. The transfer of work to these rooms has inevitably resulted in some interruption of the programme.

During the year the return of imported cereals to private trading has affected the storage position in this country and the necessity for certain types of fumigation, for example, of very large bulks of grain on floors or of large stacks of bagged grain, has diminished, at least for the time being. While this simplifies our problems in this country, the need for advice on such methods in the colonial territories and elsewhere remains so that it is of some concern to the Laboratory that conditions for full scale trials may no longer be available here. However, it is probably too soon to judge how the storage situation will develop.

An advisory bulletin " Fumigation with methyl bromide under gas proof sheets "* has been completed and published by H.M. Stationery Office.

FUMIGATION OF FLOUR WITH METHYL BROMIDE

During tests carried out in 1945 by the Laboratory in collaboration with the Research Association of British Flour Millers, it was shown that bagged flour could be satisfactorily fumigated with methyl bromide without effect upon the baking quality except that a slight foreign smell might be detected in the freshly cut loaves. There have not been many occasions when flour intended for baking has required to be fumigated and, in general, the use of methyl bromide has been avoided. Recently, however, there has been renewed interest in the possibility of fumigating stacks of bagged flour with methyl bromide either against insects and mites or, at a lower dose, against rodents. It was decided to carry out further tests to determine whether the taint produced, if any, is of normal commercial significance. Treatments were carried out by the Laboratory on white and National flours in normal cotton flour sacks at a high dose, giving concentration time products between 325 and 420 mg h per litre and a low dose giving products between 80 and 115. After fumigation the bags were allowed to stand in a large room for nine days. Samples of flour were then removed from the centre and surface of each bag, placed in sealed polyethylene bags, and, with control samples, submitted for examination by the following Laboratories:

(1) The Research Association of British Flour-Millers, Cereals Research Station, St. Albans.

(2) The British Baking Industries Research Association, Research Station, Chorleywood.

(3) Messrs. Joseph Rank, Ltd., Central Laboratory, London.

(4) Messrs. Allied Bakeries Research Laboratories Ltd., Dagenham.

At each laboratory loaves were baked and tests for taste and smell performed by special panels, using an agreed procedure. It was concluded that no taint of commercial importance was present in any of the samples.

The distribution of fumigant in a large stack of bagged flour remains to be investigated. (*W. Burns Brown*, *H. K. Heseltine*, *J. D. Pearson*).

SORPTION OF FUMIGANTS BY DIFFERENT COMMODITIES

Information on the sorption of fumigants by different commodities has been obtained by several techniques.

Work has continued on the small-scale experimental determination of the sorption of carbon tetrachloride by different grains. These tests were made in

* BURNS BROWN, W., Fumigation with Methyl Bromide under Gas-Proof Sheets. *Pest Infestation Research Bulletin No. 1*, London, 1954, H.M. Stationery Office. (2*s*. 6*d*.)

5-litre flasks. From isotherms determined at 15°C curves were drawn showing rates of sorption for a constant concentration of 100 mg per litre. These showed a very wide variation of sorption by the different grains ranging from 180 parts per million sorbed by a sample of barley in seven days to 1,500 p.p.m. by a sample of unpolished rice, with oats, wheat, sorghum and yellow maize intermediate in that order. Preliminary results with methyl bromide using a similar technique also show important variations in sorption between different grains with the barley again showing the lowest sorption and the yellow maize and unpolished rice the highest. (*S. G. Heuser, Mrs. C. E. Freeman*).

In an attempt to obtain sorption data which could be used directly for the calculation of commercial dosage schedules a series of fumigations of different commodities with methyl bromide has been carried out in a small chamber of 165 litres capacity. For each commodity at least two fumigations have been carried out, one of a bag containing 80 lb. and another of a bag containing half this amount. All tests were made at 20°C using the same dose of fumigant (4·1 g) and concentration-time products for the 24 hour period were determined in the free space and at the centre of the bag. The results agreed with those given by the smaller scale laboratory tests in that the sorption by oats and wheat was about twice that by barley, and sorption by yellow maize was about twice that by wheat. Sorption by polished rice was low, being about the same as that by barley in contrast to the high sorption by unpolished rice found in the small-scale tests. The need for further work on rice is indicated. Much higher sorption was found on decorticated groundnuts and on rice bran. The results have allowed a re-assessment of current dosage rates for all these commodities. At the same time careful consideration has been given to the form of a dosage formula which will take into account differences of loading and to the design of experiments employing one or two bags of commodity which will provide data from which such dosage formulae can be derived. (*W. Burns Brown, H. K. Heseltine, J. D. Pearson*).

RESIDUES IN WHEAT FUMIGATED WITH ETHYLENE DIBROMIDE (cf. p. 36)

After exposure of wheat to ethylene dibromide vapour a large amount of fumigant remains physically sorbed and is removed with extreme difficulty at normal temperatures. Further investigation of methods for the determination of this residual bromide was undertaken and a satisfactory technique was found which could be used in airing experiments.

Curves showing rates of airing for whole wheat and ground wheat were drawn using (a) quantity of fumigant recovered during continuous aeration and (b) quantity of fumigant retained by wheat. The extreme slowness with which the fumigant is recovered by continuous aeration from whole wheat is shown by the following data obtained from an experiment in which 10 g of wheat were exposed to 50 mg of ethylene dibromide in a litre vessel for 24 hours at 15 C.

Period of aeration, h	1	2	4	7	24	96	168
Total residual Br as $C_2H_4Br_2$, p.p.m.	1640	1510	1370	1250	1020	660	625

To determine whether or not the fumigant remaining associated with wheat was chemically unchanged it was first necessary to achieve complete removal of volatile fumigant by aeration. This appeared impracticable in any normal period with the whole wheat or even the coarsely ground material used in the above tests.

National flour was therefore chosen for exposure tests and on aeration it was found that no further reduction of bromide content occurred after 21 days, when it had been reduced to a low level (see table below). Aqueous extraction showed this residue to be completely water-soluble. It was later shown that almost all this water-soluble bromide could be detected by water extraction of the flour after only 48 hours airing, when total bromide was about 1000 p.p.m. Thus, although ethylene dibromide is normally very slightly soluble in water at room temperature, it appears to be so tightly held by the sorbent that, after preliminary airing, leaching has no effect. The water-soluble fraction must therefore be the result of a chemical reaction, which continues slightly during airing.

Attempts to extract the water-soluble fraction after only 1 or 3 hours airing resulted in an increase of bromide content in the extract over the total bromide found by ashing after complete aeration. It is concluded that some of the more loosely held ethylene dibromide was in this case removed in the extraction liquid.

In a further test, flour exposed in a chamber to a constant concentration of fumigant followed by aeration, showed a slight increase of water-soluble bromide with increasing length of exposure.

c x t mg.h/l $C_2H_4Br_2$	Water-soluble Br after 48 h aeration p.p.m.	Total Br content after complete aeration p.p.m.
2535 (72 h)	29	32
5780 (168 h)	39	44
9620 (288 h)	60	70

(*S. G. Heuser, Mrs. C. E. Freeman*).

DETECTION AND ESTIMATION OF HALOGENATED HYDROCARBONS IN AIR

1. An instrument made in the U.S.A. for the detection and roughly quantitative estimation of halogenated hydrocarbons in air has been obtained through the Mutual Security Agency. It uses the same principle as the ordinary halide lamp. An arc struck between copper and platinum electrodes varies in colour according to the amount of halogen compound present in the atmosphere. The colour is estimated by a photocell the output being shown upon a meter which can be calibrated for different compounds. The instrument has been tested with known concentrations of methyl bromide and of ethylene dichloride and calibration curves prepared. For a field instrument it appears to be reasonably accurate and reliable. Unfortunately the sensitivity depends on the number of halogen atoms in the molecule so that the sensitivity for methyl bromide is low compared with that for, say, carbon tetrachloride. The instrument is almost certainly too costly for use by the commercial fumigator.

2. A " Leak Detector " of British manufacture has been tested which depends upon the increase of positive ion current from a heated platinum anode when air containing halogen vapour is drawn between the electrodes. The halogenated compound is decomposed by the heat from the anode. The amplified current is used to give audible warning of the presence of vapour by means of a buzzer. A few parts per million of methyl bromide in air can normally be

detected. Although the makers do not claim that the instrument can be used for quantitative measurements, it was hoped that by adjustment of the sensitivity control which is provided, the detector could be arranged to buzz at chosen concentrations. However, it appears that the response of the detector is much too variable for the instrument to be used quantitatively. It can be used in place of a halide lamp for leak detection.

3. An instrument of the gas thermal conductivity type for the estimation of methyl bromide in the range of concentrations used in fumigation practice has been obtained from a British manufacturer. A full-scale deflection is given by 1·5 per cent by volume of methyl bromide in air (about 60 mg per litre). It could be calibrated for certain other fumigants if necessary. Although it has already proved of use in field and laboratory work, the instrument in its present form has an inconveniently slow response requiring up to 10 minutes to obtain a reading. It is hoped that this objection can be overcome and the instrument should then be of considerable value to commercial fumigators or other investigators who may wish to determine concentrations but are not in a position to employ more difficult methods of gas-sampling and chemical analysis.

4. The Laboratory has taken delivery of a single beam infra-red spectrometer. For some time difficulty has been experienced in determining by chemical analysis concentrations of the components of the mixtures of halogenated hydrocarbons which are being tested for various types of fumigation. The use of the infra-red instrument for these analyses is being investigated. The instrument has been checked and calibrated and suitable absorption peaks selected for the analysis of mixtures of carbon tetrachloride and ethylene dichloride in a solvent such as cyclohexane. Work is in progress to find suitable methods of sampling. (*H. K. Heseltine, J. D. Pearson*).

FUMIGATION OF H.M.S. *VICTORY*

The study and control of the infestation of the timbers of H.M.S. *Victory* by the Death-watch beetle, *Xestobium rufovillosum*, has been the concern of the Forest Products Research Laboratory for some years. Discussions held in 1953 between the Portsmouth Dockyard authorities and representatives of the Forest Products Research Laboratory and of this Laboratory led to the decision that as an additional control measure, the whole ship should be sealed and fumigated with methyl bromide.

The fumigation was carried out by a servicing company in April 1954, after the completion of an elaborate sealing programme by the dockyard staff. The volume treated was estimated to be about 330 000 cu. ft and the dose of fumigant was 990 lb. During the fumigation tests were carried out by the two interested Laboratories. Chemical work by this Laboratory included the measurement of gas concentrations at various points in the ship by the usual methods and also by the use of the instruments described elsewhere in this report. With these instruments it was possible to obtain immediate readings of the concentrations at selected points in the ship, and at points outside the hull where leakage was considerable. The fumigation was ended after about 45 hours when these tests had shown that the concentration in the ship had fallen to a very low level. Some tests were made to investigate the penetration of the fumigant through timber by placing in the ship wood blocks of various

dimensions containing cages of test insects. (Plate III (A)). The tests by this laboratory were made with adults of *Calandra granaria* and *Tribolium confusum*. species for which data on resistance to methyl bromide are available.

The numbers of Death-watch beetles found by the ship's staff during the period of emergence following the fumigation have been much smaller than in previous years. A decision has yet to be taken whether or not to repeat the fumigation. (*W. Burns Brown, H. K. Heseltine, J. D. Pearson, Miss B. D. Hole*).

STOCKS OF INSECTS FOR TESTING THE TOXICITY OF FUMIGANTS

Stocks of eighteen species of insects are being maintained and the pre-adult stages of these present culturing problems which do not arise when only adults are used as test insects.

The quality of the test insects, and therefore the value of the toxicity data obtained with them, depend so largely on the care with which culturing methods are worked out that a good deal of time is spent on this side of the work. This year several improvements have greatly increased efficiency. Improved temperature control in the 25°C constant temperature room has made it easier to ensure that pre-adults at a specified stage of development will be available at the date of the test and greater attention has been paid to the moisture content of the foods which are used. The use of a small new laboratory specially equipped for culturing has facilitated the work and simplified the precautions which are taken against infestation by mites. An occasional infested culture would not be serious were it not for the fact that mites increase and spread so rapidly in the constant temperature room that a large number of cultures have been lost as the result of the introduction of a single infested culture. A very successful solution to this difficulty was suggested by Miss P. L. Robertson. Instead of the muslin tops for culture jars circles of filter paper are used and are sealed with paraffin wax to provide a mite-proof cover. Tests have shown that ventilation through a paper is satisfactory and the method has now been in general use for all the cultures for nearly twelve months. (*Miss E. M. Reynolds, Miss M. F. East*).

TOXICITY OF METHYL BROMIDE TO INSECTS

From the results of earlier tests made with *Calandra granaria*, adults and pre-adults, *Calandra oryzae* adults and pre-adults, *Tribolium confusum* adults and pupae, *Tribolium castaneum* adults, *Ptinus tectus* adults and cocoons, *Laemophloeus minutus* cocoons, *Oryzaephilus surinamensis* adults, *Rhizopertha dominica* adults, and *Trogoderma granarium* larvae the following concentration-time (c.t.) products in mg h per litre, were estimated for not less than 99.9 per cent kill of any of the above species.

°C	*mg h per litre*
10	200
15	180
20	150
25	100

This year further tests have been made using *Carpophilus dimidiatus* adults. *Araecerus fasciculatus* adults, *Gnathocerus cornutus* adults, *Callosobruchus chinensis* pre-adults, *Oryzaephilus mercator* adults, *Lasioderma serricorne*

cocoons, *Ptinus tectus* eggs, *Stegobium paniceum* cocoons, *Tribolium castaneum* pupae and *Tribolium confusum* eggs. Some of these have only been tested at 25°C but, with the possible exception of *L. serricorne* cocoons at 10°C no evidence has been obtained to suggest that the c.t. products quoted above would be insufficient for any species tested so far. (*Miss E. M. Reynolds, Mrs. B. M. Reynolds, Miss M. F. East*).

Increased accuracy of dosing has been achieved in these tests by obtaining the correct weight of methyl bromide in a small closed vessel from which it could be vaporized into the chamber. This method was first used in the tests under reduced pressure. As in all the toxicity tests the concentrations obtained in the chamber were checked by withdrawal and analysis of gas-samples. (*S. G. Heuser, Mrs. C. E. Freeman*).

EFFECT OF TEMPERATURE ON THE RESISTANCE OF *Calandra granaria* ADULTS TO ETHYLENE DICHLORIDE

Further tests have been made on the effect of temperature on the toxicity of ethylene dichloride (1, 2-dichloroethane) to adult *C. granaria*. Earlier work had shown that *C. granaria* adults kept after fumigation at 25°C are able to recover from a condition which would prove lethal at 10°C. It had also been found that whereas at 25°C there was no further mortality among any insects which survived the first week following fumigation, mortality continued to increase at 10°C for about ten weeks. Tests have been made this year to confirm these effects of temperature on recovery after longer exposure to lower concentrations of fumigant than were used in the earlier work. In addition some information was obtained about the effect on recovery of delays of from two to thirty-two days after fumigation before changing the temperature. It has been found that recovery also takes place at 15°C but more slowly than at 25°C. It has also been found that keeping fumigated samples at 10°C delays the mortality of those insects which are so severely affected that they are unable to recover at 25°C. The differences between the times taken after fumigation for mortality to reach its final level appear to be due to a decrease, with decrease in temperature, in the rate of response to the fumigant whether in the direction of recovery or death. (*Miss E. M. Reynolds, Mrs. B. M. Reynolds*).

TOXICITY OF METHYL BROMIDE UNDER REDUCED PRESSURES

The current programme of tests on the toxicity of methyl bromide at reduced pressures which was described in last year's Annual Report (p. 27) has been completed by three more series of tests and the results are being analysed. The aim of these tests was to compare two procedures for vacuum fumigation which had been the subject of earlier tests on penetration of methyl bromide into various products. In one method the reduced pressure was sustained for the full exposure period of 4 hours whilst in the second the pressure was restored to atmospheric after one hour. In these tests all stages of *Calandra granaria* were included and it appears that, although a substantial kill of this species under the conditions of either of the two vacuum methods tested would be obtained by lower c.t. products than would be needed for a similar kill at atmospheric pressure, the c.t. product required for 99·9 per cent kill by either vacuum method is usually very similar to that needed at atmospheric pressure. The order of resistance of the immature stages which occur inside the wheat grains, differs in the various methods. At atmospheric pressure the older are the most resistant

to methyl bromide. The sustained vacuum method has the effect of reducing the resistance of these older stages to below that of the younger stages at doses which give a high level of kill. The younger stages (presumably eggs) are by this method the most resistant so that it is possible for a very small proportion of eggs to survive fumigations which appear to be successful asde termined by normal post-fumigation inspection methods. By the method in which the pressure is restored to atmospheric after the first hour this effect was not usually obtained although a tendency in this direction was found in tests at 7 cm of mercury.

In last year's Annual Report it was noted that the effect of the level of reduced pressure (15 cm or 7 cm of mercury) differed in the two vacuum methods. The results so far obtained do not indicate how great is the effect of these differences on dosage for 99·9 per cent kill, but it is of obvious practical importance that a level of pressure below which toxicity ceases to increase is sometimes reached at pressures within the range of those used commercially. There seems a reasonable possibility that information about the effect on rate of respiration of the oxygen deficiencies which are created by reduced pressures might prove helpful in interpreting some of the differences which have been found. An apparatus has been constructed in which the rate of oxygen uptake by samples of about 100 insects at pressures between atmospheric and about 5 cm Hg can be measured. (*Miss E. M. Reynolds, S. G. Heuser, Mrs. B. M. Reynolds, Miss M. F. East, Mrs. C. E. Freeman*).

RESISTANCE OF *Trogoderma granarium* TO FUMIGANTS

A special study of the resistance of *Trogoderma granarium* is being made. From data obtained at 32°C and 70 per cent R.H. with fully grown larvae a c.t. product of 66 mg h per litre of methyl bromide has been estimated for 99·9 per cent kill. This estimate compares with an earlier one of 100 mg h per litre at 25°C and 70 per cent R.H.

An investigation into the resistance of the long-lived larvae described earlier in this report (p. 9) is in progress. (*Mrs. B. M. Reynolds, Miss M. F. East*).

USE OF TEST INSECTS IN FUMIGATION TRIALS

In last year's report reference was made to the value of pre-adult stages of *Calandra granaria* as test insects in assessing the effectiveness of fumigation of large bulks of grain. Few opportunities have occurred during the past year to make use of this method of assessment.

Test cages containing the pre-adults of *C. granaria* in grain and also cages of the adults were used in a fumigation of part of a large bulk of home-grown wheat stored on a floor within bulkheads of bagged grain. The surface of the bulk was sprayed at the rate of 1 gallon to about 5 tons of grain with a 1 : 1 by volume mixture of ethylene dichloride and carbon tetrachloride with 5 per cent of ethylene dibromide added. The temperature in much of the bulk lay between 5° and 13°C and survivals in the test insects were valuable in showing where the treatment made under these adverse conditions had been ineffective.

The Laboratory was desirous of carrying out trial fumigations of grain in farm-type silo bins using chlorohydrocarbon mixtures and had arranged to treat experimentally four bins of various types at the National Institute of Agricultural Engineering, Silsoe. A complication arose when it was found that

the grain in these bins was heavily infested by mites. The programme of tests was modified in the hope of controlling these mites. The bins were sealed as far as was practicable and the fumigant mixture used in the bulk treatment described above but containing 10 per cent ethylene dibromide was employed, 5 gallons being used for each 20-ton bin. The pre-adult stages of *C. granaria* were used as test insects, and, in addition, cages containing all stages of *Tyroglyphus farinae* were used. There were no survivals of insects and only a very few survivals of young stage mites in two of the 36 mite cages used. The control of mites in the bins was very good. One of the bins was constructed from galvanized steel and a little corrosion was noticed near the grain surface after the treatment. Laboratory tests indicate that this corrosion could have been caused by the ethylene dibromide in the fumigant mixture. (*Miss B. D. Hole*).

BIOCHEMISTRY

The work of the section has progressed especially well during the year and this has been due largely to the greatly improved conditions of space and laboratory organization possible in the new building.

A—STUDIES ON THE NATURE AND SIGNIFICANCE OF INSECTICIDE RESIDUES IN FOODSTUFFS

In their recent report* on toxic chemicals in agriculture, a working party under the chairmanship of Professor Zuckerman expressed concern about the use of certain insecticides " not because they necessarily present any greater hazard, but because the information does not exist on which to base an estimate of the risk they constitute ". The work under A is designed to provide this type of information for insecticides and fumigants which may come into contact with stored food products.

METHYL BROMIDE RESIDUES IN WHEAT

These studies have been completed and prepared for publication. As a result of this work and of the co-operation of Dr. J. M. Barnes of the M.R.C. Toxicology Unit, of Dr. J. Pace of the Research Association of British Flour-Millers and of Drs. E. Kodicek and M. Clegg of the Dunn Nutritional Laboratories, Cambridge, it has been possible to make an appraisal of the possible toxicological and nutritional implications of fumigating wheat with methyl bromide. This work has shown that as a result of eating fumigated wheat or flour products and neglecting possible chemical decomposition as a result of baking, cooking etc. (which is likely to reduce the effectiveness of toxic substances) traces of the following substances would be absorbed:—

Inorganic bromide
Methyl methionine sulphonium salts
1–methyl histidine
3–methyl histidine

* Toxic Chemicals in Agriculture—Residues in Food. Report of the Working Party on Precautionary Measures Against Toxic Chemicals Used in Agriculture, 1953. Ministry of Agriculture and Fisheries, H.M. Stationery Office. 1*s*. 6*d*. net.

Methanol
Methylated glucoses
S–methyl cysteine
Dimethyl histidine salts
ϵ–N–Methyl lysine
Unidentified substances

It is estimated that in the extreme (and unlikely) case of a person consuming bread and flour products made only from fumigated wheat the rate of absorption of these compounds would not together exceed 175 mg per week. Many of these compounds have been synthesized and fed or injected into mammals at doses greatly in excess of those likely to result from fumigation practice. In some cases the metabolic fate of the substance has been studied. The major end-products of digestive hydrolysis, represented by bromide, sulphonium salts and methyl histidine, which account for some 70 per cent of the methyl bromide decomposition, products are established natural constituents of common diet. The experimental and published data suggest that most of the remaining compounds would be quite innocuous at the concentrations obtaining in fumigated food products. Finally it has been shown that the fumigation of wheat with methyl bromide will not significantly affect its nutritional value by the destruction of essential food constituents such as amino acids and certain B-vitamins. (*F. P. W. Winteringham, S. E. Lewis, R. G. Bridges, A. Harrison, Mrs. P. M. Bridges*).

ETHYLENE DIBROMIDE RESIDUES IN FUMIGATED WHEAT

Preliminary experiments on the nature of ethylene dibromide residues in fumigated ground wheat have been made using bromine-82 labelled ethylene dibromide. Results, confirming those of Mr. S. G. Heuser of the Fumigant Section (p. 29), have shown that in spite of the large physical sorption of the fumigant by the ground wheat the amount of chemical reaction, as determined by the water-soluble bromide, is small. This amount of water-soluble bromide is considerably increased when the flour is heated to simulate baking. At this stage it is not possible to say whether heating causes an increased amount of chemical reaction to take place between the sorbed fumigant and the flour or an increased spontaneous decomposition of the former. About one-third of the initial residue was still retained by the flour after passing a stream of air through the bulk for 14 days. However, this residue slowly aired off when the flour was spread out in a thin layer. This suggests that, under relatively poor conditions of airing considerable amounts of the fumigant may be retained by the food product. (*R. G. Bridges*).

B—STUDIES ON MECHANISMS OF INSECTICIDAL ACTION

The work under this title may be described as " long-term " in so far as it is not expected to yield results which are immediately applicable to the problems of insect pest control. It is designed to contribute to the ultimate solution of such problems as the natural or acquired tolerance of some insect species to insecticides, the safer application of existing insecticides (and fumigants), or the development of more selective insecticides. However, because of its fundamental nature, this work and the techniques developed for its progress are likely not

only to be useful in the problems of safe insect control, but in such problems as the control of toxic hazards in industry or the pharmacology of drugs. Separate lines of attack are being simultaneously followed in the belief that this particular work thrives best in an atmosphere of diverse rather than unified interests. These lines are:

(1) Study of the absorption and metabolism of the insecticide by the exposed insect

(2) Biochemical effects of the insecticide *in vivo*

(3) Biochemical effects of the insecticide *in vitro*

(4) Comparative aspects of insect biochemistry and physiology relevant to insecticidal action

The importance of (1) in the problems of resistance and synergism is well established. The dual approach of (2) and (3) provides an invaluable check on theories of toxic action based on one approach only. Studies under (4) are fundamental to the study of selective toxicity. The following items of the current year's work illustrate this multiple approach.

ABSORPTION AND METABOLISM OF ^{14}C-LABELLED PYRETHRINS AND ALLETHRIN BY ADULT HOUSEFLIES; EFFECTS OF SYNERGISTS

The first programme of work under this heading has now been completed and the results will be prepared for more detailed publication elsewhere. (see also the Annual Reports for 1952 and 1953). The following conclusions have been drawn from this work:—

(i) When a natural mixture of pyrethrins and cinerins I and II was applied topically to the mesonota of adult houseflies the I- and II-esters penetrated the integument at approximately equal rates.

(ii) When applied topically in acetone the absorption of pyrethrins and of allethrin by adult houseflies was more efficient than that of a bromine analogue of DDT (and probably, therefore, more efficient than that of DDT itself) under the same conditions.
For example, when 1 μg of the insecticide was applied in 1 μl. of acetone approximately 30 per cent of the DDT analogue remained on the external surface of the insect while only 2·4 per cent of allethrin so remained.

(iii) In the presence of the synergist piperonyl cyclonene the penetration of topically applied allethrin was significantly reduced. For example, of 1μg of topically-applied allethrin 2·4 per cent remained on the outside of the insect. In the presence of 5μg of synergist 11·7 per cent remained on the outside while in the presence of 10 μg of synergist 18·4 per cent remained on the outside. The significance of this unexpected phenomenon is not yet clear.

(iv) When the natural mixture, or a chromatographic preparation of the I-esters from the natural mixture was applied topically to, or injected into adult houseflies the insecticide was rapidly metabolized. Topically applied allethrin was similarly metabolized. The metabolism in all cases was either partly or completely inhibited in the presence of an excess of piperonyl cyclonene and the flies succumbed more rapidly. That the metabolism is enzymic in nature was suggested by the fact that it failed to occur in flies which had been killed by brief immersion in hot water before treatment.

(v) The recovery of the natural esters or of allethrin in tissue extracts rarely exceeded 60 per cent whether extraction was made in water, acid, alcohol, acetone or ether from neutral or acid homogenates. The remaining insecticide or its metabolites were invariably found in the insoluble fraction of the tissues.

The results strongly support the hypothesis that the synergistic mechanism involves the inhibition of a natural detoxication mechanism. Surprisingly, (see Annual Report for 1952) allethrin was apparently metabolized about as fast as the pyrethrin esters in the adult houseflies but its metabolism was not so effectively inhibited by piperonyl cyclonene as that of the natural esters. This would explain the less effective synergism between allethrin and piperonyl cyclonene. (*F. P. W. Winteringham, A. Harrison, Mrs. P. M. Bridges*).

EFFECTS OF INSECTICIDES ON THE PHOSPHORUS METABOLISM OF THE ADULT HOUSEFLY *in vivo*

Studies have progressed steadily during the year by preliminary observations on the effects of DDT and of some halogenated hydrocarbon fumigants. Details of the method are in the press (*Biochemical Journal*, 1955).

DDT applied topically in acetone to adult houseflies had no effect on the distribution of the soluble phosphorylated intermediates of thoracic tissue after 1 h or 5 h although the flies exhibited the usual excessive motor activity. However, when the insects were spared the excessive motor activity by sustained cyclopropane anaesthesia there was a marked reduction in the level of tissue adenosine triphosphate (ATP). For example the effect of a 5-h exposure is shown below. Cyclopropane or acetone alone were without effect.

	Normal flies [*Control; acetone only*]	*Hypermotor active flies* [0·25µg *DDT in acetone*]	*Anaesthetized flies* [0·25 µg *DDT in acetone; continuous cyclopropane anaesthesia*]
Intermediate	Phosphorus of intermediate as per cent total soluble phosphorus		
Adenosine triphosphate	44·2	42·2	19·4
Adenosine diphosphate	3·3	0	0
Arginine phosphoric acid	9·2	12·9	10.0
Adenylic acid + Unknown	2·5	4·0	2·7
Glucose-6-phosphate	11·4	7·8	8·2
Phosphoglycerate	19·7	12·7	7·6
Phosphate	9·7	20·4	52·1
	100·0	100·0	100·0

The results shed light on the interesting observation by Merril, Savit and Tobias* that cockroaches spared the excessive motor activity of a DDT treatment by prolonged anaesthesia went on to die as though they had not been spared that activity. These results show that the combined effect of DDT and

* *J. Cellular and Comparative Physiology*, 1946, **28**, 465.

cyclopropane is a marked depletion in ATP level so that on recovery from the anaesthetic the insect may be unable to utilize otherwise intact carbohydrate reserves. Another point of interest is that although DDT alone stimulates respiratory activity *in vivo* (an expected consequence of the induced motor activity) there is no uncoupling of oxidative phosphorylation as would be expected with dinitrophenol for example which also stimulates respiratory activity.

Methyl bromide caused a drastic reduction in adenosine triphosphate (ATP) and arginine phosphoric acid levels within minutes of exposure and the insects were completely immobilized. The insects recovered temporarily in fresh air as did the levels of ATP and arginine phosphoric acid. A delayed effect of methyl bromide was the depletion of phosphoglycerate which was consistent with the inhibition of triosephosphate dehydrogenase, a likely consequence of SH blocking *in vivo*. This was apparently the lethal biochemical lesion. Ethylene dibromide was without effect on ATP but, like methyl bromide, caused a slow and apparently lethal depletion of phosphoglycerate. Ethylene dichloride, like cyclopropane alone, induced deep narcosis within minutes of exposure without significant effect on any phosphorylated intermediate. This would not be expected from the views of Johnson and Quastel* that narcotics "impede the oxidative synthesis" of ATP and suggest that narcotic action does not necessarily involve a significant effect on the phosphorylation of nucleotide acceptors *in vivo*.

Although both methyl bromide and ethylene dichloride rapidly immobilized the exposed insects the effects observed on the phosphorus metabolism suggested quite different mechanisms of action. The spectacular depletion of tissue ATP by methyl bromide would be expected to prevent normal muscle action since this certainly depends on the high energy phosphate bonds of ATP and phosphagen. Ethylene dichloride, however, was without effect on the muscle phosphorus and the immobility of the insect was apparently due to narcosis of the nervous system. These interpretations were tested experimentally. Adult flies were impaled on a pair of needle electrodes which penetrated two millimetres or so into the thoracic tissue (mainly indirect flight muscle). A normal fly responds vigorously by leg and wing movements, to a low current pulse applied across the electrodes. Flies which were otherwise quite immobile as a result of exposing them to ethylene dichloride or to cyclopropane also respond vigorously to the Faradic stimulus, suggesting normal muscle function. Flies immobilized by methyl bromide exposure, however, failed to respond confirming a direct blocking of muscle function. These experiments also further suggested that deep narcosis of the insect had not involved any interference with ATP synthesis *in vivo*. (*F. P. W. Winteringham, G. C. Hellyer, Mrs. P. M. Bridges, Miss A. Weatherley*).

AEROBIC METABOLISM IN INSECT MUSCLE, *in vitro* STUDIES

The indirect flight muscles of many insects contain large numbers of granules known as sarcosomes, which were first described in 1853, but it was not until 1951 that these sarcosomes were shown to contain most of the enzyme systems involved in the aerobic metabolism of the muscle and to resemble the mitochrondria of other cells. More recently it has been possible to demonstrate in

* *Nature*, 1953, **171**, 602.

these sarcosomes the phosphorylation reactions which are generally believed to accompany, and possibly control, aerobic metabolism *in vivo*.

The sarcosomes used in the present study were isolated from the blowfly *Calliphora erythrocephala*, and were usually suspended in a sucrose solution containing the chelating agent ethylenediamine tetra-acetic acid. Their aerobic metabolism in the presence of various substrates has been investigated by conventional manometric methods. Physical changes associated with the medium in which they were suspended have been studied by a light scattering technique previously used in the study of red blood corpuscles.

Succinic oxidase system

Although the sarcosomes contain comparatively large amounts of cytochrome *c*, they oxidize succinate rather slowly unless more cytochrome *c* is added. Either the endogenous cytochrome c is not readily available, or the rate of oxidation is limited by some other reaction. A similar stimulation of oxygen uptake was produced by breaking up the sarcosomes and in these preparations added cytochrome *c* had little effect. The occurrence of a rate-limiting reaction has been observed in preparations to which cytochrome *c* was added and has been ascribed to the accumulation of oxaloacetate, since this substance is a well known inhibitor of the succinic oxidase system. The probable mechanism is best illustrated in the simplified scheme shown below.

$$\begin{array}{ccccccc} \text{Succinate} & \longrightarrow & \text{Fumarate} & \longrightarrow & \text{Malate} & \xrightarrow{\text{[coenzyme I]}} & \text{Oxaloacetate} \\ & & & & & & \downarrow Mn^{++} \\ & & & & & & \text{Pyruvate} \end{array}$$

The inhibition, believed to be due to oxaloacetate may be partially removed by the addition of manganese ions which are known to be an essential component of the oxaloacetate decarboxylase system. The effect of manganese was much more pronounced in whole muscle preparations, which suggests that the decarboxylase system is either lost from the sarcosomes during the isolation procedure or that it is more concentrated in the sarcoplasm.

Malate oxidation

Here again the rate of oxidation could be increased by the addition of cytochrome *c* and also by the addition of coenzyme I or manganese. In contrast to succinate oxidation, malate oxidation decreases in sarcosomes which have been stored for some hours after isolation. This effect is presumably due to the loss of endogenous coenzyme I since addition of this factor restored the original activity.

Physical changes

It has been reported that when sarcosomes are suspended in a potassium chloride solution which is isotonic with insect haemolymph they swell rapidly. It has been found that this effect can usually be eliminated by incorporating ethylenediamine tetra-acetic acid in the solution used to isolate the sarcosomes. Swelling could not be prevented if this substance was added after the sarcosomes had been isolated. The presence of 0·1 per cent bovine plasma albumin in the

potassium chloride solution also prevented this abnormal swelling and has previously been shown to stimulate the oxidation of α-ketoglutarate and the accompanying phosphorylating reactions. When a small quantity of adenosine triphosphate was added to the potassium chloride solution a preliminary swelling of the sarcosomes occurred followed by a shrinkage and a return to their original size. Reports describing this effect of adenosine triphosphate on vertebrate mitochondria have recently appeared in the literature. (*S. E. Lewis, G. M. Price, K. S. Fowler*).

ACETYLCHOLINE IN INSECTS

Separation and identification of acetylcholine in insects

In chromatographic studies of the acetylcholine-like activity in partially purified extracts from blowflies earlier results indicated comparable R_F values for the active substance and acetylcholine and no signs of separation were observed. The chromatograms were run in a propanol/formic acid/water solvent. In butanol/water, however, the activity of the extract runs with R_F 0·5–0·6 compared with *ca.* 0·1 for pure acetylcholine. When the latter is co-chromatographed with the extract, pharmacological assay of sections of the strip shows that part of the added acetylcholine runs together with the active substance of the extract and part where acetylcholine might be expected at the lower R_F. This is not likely to be due to the effect of salts since these should be absent and in any case the anomaly persists when the active substance is eluted from one chromatogram and re-run on a second strip. This uncertainty was also apparent with some butanol/acetic acid solvents, while in some experiments using butanol strongly acidified with hydrochloric acid the activity disappeared during the run.

By the kindness of Professor J. H. Burn, Dept. of Pharmacology, Oxford, some differential assays on the partially purified extract have been carried out. These again are not conclusive though it would seem that discrepancies are more likely to be due to impurities rather than to the presence of a choline ester other than acetylcholine.

A crystalline dipicrylamine derivative has been isolated which shows pharmacological activity on the frog rectus muscle preparation. This derivative is undoubtedly composed of mixed crystals of the dipicrylaminates of choline and a choline ester. Consideration of the comparative purity of the substance and the amount of pharmacological activity present, taken together with the result of the differential assay, point to the identity of the choline ester with acetylcholine.

Methods of extraction

Experience has shown that the existing methods for the determination of acetylcholine in tissues can give variable results when applied to insects. In order to establish the significance of these variations and to obtain a true measure of the concentration of acetylcholine *in vivo*, various methods of extraction are being compared on the blowfly *Calliphora erythrocephala*. Treatment of the insects with liquid nitrogen before extraction results in a marked reduction in the amount of acetylcholine found in the extract. Again the concentration of eserin in the extraction medium and the time of heating after extraction appear to have significant effects. (*S. E. Lewis, K. S. Fowler, K. H. Hallowes*).

C—MISCELLANEOUS WORK FUNDAMENTAL TO A AND B

SYNTHESIS AND SEPARATION OF N-METHYLATED HISTIDINES

For the purpose of acute mammalian toxicity tests a mixture of the three N-methyl histidines previously shown to be present in the acid hydrolysate of methyl bromide-fumigated flour was prepared by methylation of phthaloyl-histidine followed by hydrolysis. The three methylated histidines were separated by large-scale paper chromatography. (*R. G. Bridges*).

PREPARATION OF CARBON-14 AND BROMINE-82 LABELLED ETHYLENE DIBROMIDE

For studying the nature of ethylene dibromide residues in fumigated wheat methods for the preparation of the labelled fumigant on the millimole scale have been developed. Starting with ^{14}C-labelled ethanol, the labelled fumigant can be obtained in a 70 per cent overall yield by the following series of reactions:

$$CH_3.\ C^*H_2OH \xrightarrow[360^\circ C]{\text{alumina}} CH_2{:}C^*H_2 \xrightarrow{Br_2} CH_2Br.\ C^*H_2Br$$

Starting with ^{82}Br-labelled potassium bromide the labelled fumigant has been prepared as follows:—

$$K\ Br^* \xrightarrow[H_2SO_4]{K_2Cr_2O_7} Br^*_2 \xrightarrow{C_2H_4} CH_2Br^*\ .\ CH_2Br^*$$

(*R. G. Bridges*).

A 4-π COUNTER FOR QUANTITATIVELY SCANNING SOFT BETA-EMITTERS SEPARATED ON PAPER CHROMATOGRAMS

In the paper chromatographic separation of the ^{14}C-labelled metabolites of allethrin of very low specific activity a highly efficient method of radiometric scanning was required. A readily demountable 4-π counter was therefore developed in which paper chromatograms could be scanned within the sensitive volume of the counter, the paper being advanced by a simple manual control. The counter is charged with an ethanol vapour-helium mixture and operates in the Geiger region. The counter is about eight times more sensitive than a conventional thin end-window (2 mg/cm^2) G-M tube for ^{14}C-labelled compounds deposited on Whatman No. 1 paper. Tritium labelled compounds separated on Whatman No. 1 paper have also been detected with an estimated efficiency of the order of 0·2 per cent. By means of a coincidence circuit connected to the two separate regions of the counter for the detection of cosmic rays the total background counting rate has been reduced effectively to 25 c.p.m. when the counter is sheltered by 3 in. of lead. The counter provides a convenient and sensitive method for determining non-volatile ^{14}C- and ^{35}S-activities in solution. Suitable aliquots of the samples are spotted at intervals along a strip of Whatman No. 1 paper and the solvent dried off. For ^{14}C-samples on Whatman No. 1 paper (approx. 8·8 mg/cm^2) the efficiency of the counter has been estimated to be 32 per cent. The technique therefore rivals liquid scintillation counting for very small samples of solutions containing ^{14}C or ^{35}S and is probably superior at low counting rates on account of the effectively lower background. (*F. P. W. Winteringham, A. Harrison*).

LOCATION OF GLYCOGEN IN HISTOLOGICAL SECTIONS

For the purpose of studying the effects of DDT on tissue glycogen as well as upon the levels of different phosphorylated intermediates (see above) various methods for the location of glycogen in sections have been compared. The periodic acid-Schiff reaction has been successfully applied to sections prepared from chemically fixed and frozen-dried tissue. The specificity of the method was tested on sections in which glycogen had been selectively hydrolysed by the action of α-amylase. In normal adult houseflies considerable reserves of glycogen were found in indirect flight muscle, cells of the fat body and proventriculus. (*Mrs. P. M. Bridges*).

COLONIAL LIAISON

Liaison on problems of food storage with the Colonial territories continues at high pressure.

During 1954, 980 letters were received on Colonial matters and 1140 were sent out.

There have been 65 visitors from the Colonies and 17 from the U.K. to discuss food storage problems.

The Food Storage Courses for officers from Colonial territories have been given by the Ministry of Agriculture and Fisheries as in previous years. Special efforts are being made to get as many Agricultural and Storage Officers as possible to attend this Course. In the cases of officers who have already taken the Course or are desirous of some form of instruction specific to their needs, special arrangements are made to organize this with the various appropriate organizations in the U.K. During this year, 11 special programmes of instruction have been undertaken at the Laboratory. One of the entomologists (Mr. J. Riley) of the West African Stored Products Research Unit spent 3 weeks carrying out research on an aspect of cocoa with which he is specially concerned in Nigeria and Mr. P. Prevett (Colonial Stored Products Student) spent 4 weeks at the Laboratory familiarizing himself with the problems of paddy and rice storage on which he will be working in Sierra Leone for the next 2–3 years.

From March until June 1954, the Colonial Liaison Officer was on tour in the West Indies. In addition to visits to British Guiana, Trinidad, Barbados, Grenada, St. Lucia, Antigua, Jamaica, British Honduras and the Bahamas to determine the local storage problems, he spent two weeks in the rice area of the southern United States with Mr. T. A. Oxley (see p. 5).

ADVISORY WORK

Interest in pit storage of grain in Colonial territories is steadily mounting. Advice on the principles of the method together with suggestions of detailed aspects of construction, which have been obtained with the collaboration of the U.K. Building Research Station, have been given to a number of territories. The Colonial territories which have carried out or are carrying out pit storage experiments are Tanganyika, Nyasaland, Sudan, Nigeria, Gold Coast, Southern Rhodesia and Cyprus. A memorandum on pit storage which reviews the information known to date has been prepared for publication.

Gas-proof sheeting material for use under very stringent conditions such as obtain in Northern Nigeria is being tested in collaboration with the Ministry of

Supply. Sixty small gas proof sheets of (a) woven nylon coated with polyvinyl chloride or neoprene and (b) cotton coated with neoprene have been sent to Nigeria for test. Four envelopes of neoprene-coated cotton and one of polyvinyl-coated nylon to cover groundnut pyramids are being used in fumigations.

Since 1952 the National Institute of Agricultural Engineering have conducted experiments using five small 20-ton " farm " silos each made of different materials such as concrete blocks, plywood, aluminium and steel. In view of cheapness, and the lack of condensation problems with a wooden silo negotiations were started with the makers of the plywood silo with a view to determining its suitability for use in tropical territories. Arrangements have now been made for 20-ton plywood silos with specially designed roof and treated walls to be erected and tested in Nigeria, Gold Coast, Sierra Leone, Kenya, Tanganyika, Trinidad and Malaya.

Advice has been given to British Honduras on the Grading Standards for Paddy, Corn and Red Kidney Beans which they intend to establish to assist farmers in disposing of their crops. (*D. W. Hall*, *G. A. Haswell*).

The following reports and papers have been prepared:—

(a) Food Storage Problems in Northern Rhodesia.

(b) Food Storage Problems in Nyasaland.

(c) Food Storage Problems in St. Lucia.

(d) Further Observations on the Quality of Sierra Leone Groundnuts.

(e) Future Policy of Stored Products Work in Colonial Territories with special reference to the Caribbean.

(f) Food Storage Problems in Tropical Territories. (Paper read at the Jubilee Conference of the Association of Applied Biologists).

(g) The Modern Method of Hermetic Storage.

(h) A Note on the Specific Heat of Rice, Oats, and their Products.

(i) Experiments on Moisture Content Determination Methods.

SUMMARY OF MAJOR DEVELOPMENTS IN COLONIAL TERRITORIES

(a) *East Africa*

At the East Africa High Commission a Department of Produce Disposal has been set up which co-ordinates the activities of the grain storage and marketing organizations of the three East African mainland territories. A visit has been paid to East Africa by the chief instructor of the Infestation Control Division, Ministry of Agriculture and Fisheries, in order to obtain a background for the Food Storage Course for Colonial Officers held at Tolworth.

(b) *Kenya*

Experiments have been carried out at the Scott Agricultural Laboratories on the protection of maize stored on the cob in cribs using various insecticidal dusts. These indicated that in practice cobs can be dusted very heavily with BHC dusts to give control of infestation, because after mechanical shelling not more than about 1 p.p.m. of BHC remains on the grain. Experiments have also been completed on the protection afforded by admixed inert and insecticidal dusts to bagged maize against attack by *Calandra oryzae*.

(c) *Tanganyika*

Following the recent experiments with small grain storage pits, the Department of Grain Storage (D.G.S.) are constructing larger pits for famine reserves and seasonal storage. One of the experimental pits has been filled with high moisture content maize from Uganda to investigate the potentialities of this type of storage for damp grain. Two sets of equipment for fumigation under gas-proof sheets with methyl bromide are now available and the D.G.S. have had two men specially trained in the U.K. for this work.

(d) *Southern Rhodesia*

Experiments with a direct practical bearing have been carried out on the protection of stacks of maize, sorghum, and beans against insect infestation. The Grain Marketing Board have erected a 50 000 tons (short) capacity silo in conventional vertical concrete bins (each 1000 tons capacity) fitted with piping for circulatory fumigation. They are now proceeding to build a 10 000 tons silo having eight concrete bins.

(e) *Nyasaland*

A private firm has purchased the necessary equipment for gas-proof sheet fumigations with methyl bromide and has had an operator trained in this method of control in the U.K. The Produce Marketing Board's stocks of maize are now being fumigated by this method.

A Colonial Office research worker has been in Nyasaland for three years on maize storage problems and is now spending a further six months assessing the efficiency of gas-proof sheet fumigation under the local conditions.

(f) *Nigeria*

The Department of Marketing and Exports has been advised on the construction of a fumigation chamber which is being planned as part of the port facilities at Apapa. The Department has constructed Ctesiphon-type godowns and is testing their suitability for the safe storage of foodstuffs under the local conditions.

(g) *Gold Coast*

An entomologist who will concentrate primarily on stored products problems commenced work at the beginning of the year.

(h) *Gambia*

The serious effect of infestation on the quality of groundnuts was referred to in last year's report (p. 37). A senior member of the staff of the Laboratory is spending three months in the Gambia, at the invitation of that Government, investigating methods of control of the relevant insect pests.

(i) *Sierra Leone*

A Pest Control Officer has been appointed by the Department of Commerce and Industries with a view to reducing losses of stored foodstuffs.

(j) *Federation of Malaya*

The possibility of using small concrete silos for the storage of rice is under investigation.

EXPERIMENTAL WORK

On many occasions it is difficult for lack of scientific data to anticipate the behaviour and life history of certain insect species under tropical conditions. To this end an additional constant temperature and humidity room has been built, providing constant temperatures between 30°C and 33°C and a relative humidity of 70 per cent.

(a) *Water vapour Barriers for Floors of Storage Premises etc.*

The importance of the use of efficient vapour barriers in the proper storage of foodstuffs was mentioned in the 1953 Report (p. 38). Six bitumen treatments (including bitumen paint and roofing felts) and a lacquer are being tested on a concrete floor for their efficiency as water vapour proof barriers by measuring changes in the moisture content of wheat placed in contact with the treatment for a period of 6–9 months. (Plate III (B)). (*D. W. Hall, Miss P. M. Davey*).

(b) *Thermocouple Spear for Measuring Temperatures in Bag Stacks*

The development of a spear head incorporating a thermojunction insulated from the main body of the spear has been carried out. This spear head was developed for use in bagged produce. (*D. W. Hall, G. A. Haswell*).

(c) *Maize*

Acidity in maize has been the only criterion to date on which to judge the palatability or impalatability of maize meal to Africans. It largely results from attack by fungi and insects. Arrangements have been made with the Colonial Products Laboratory (C.P.L.) for the necessary acidity analyses to be carried out on samples of infested maize and, as a preliminary to a large-scale experiment, samples of maize have been subjected to attack by *Tribolium castaneum* for 3 months at 30°C and 70 per cent relative humidity. (*D. W. Hall, Miss P. M. Davey*).

The contamination of African maize meal with insect fragments and rodent hairs was referred to in last year's report. The collaboration of the C.P.L. was sought to develop a reasonably accurate method of assessing the degree of contamination to enable analysts in the various territories to carry out their own tests. The C.P.L. are investigating this with the help of the British Food Manufacturing Industries Research Association and the British Baking Industries Research Association, and although a sample dilution method has been investigated in some detail the problem is still under consideration. (*D. W. Hall, R. W. Howe*).

(d) *Effect of Insect Attack on Groundnut Acidity and Protein*

Work under this heading has continued during the year with the collaboration of the C.P.L. Experiments using *Tribolium castaneum* adults and larvae, *Trogoderma granarium* larvae and *Caryedon fuscus* larvae are being carried out in more detail than in the preliminary experiments recorded in last year's report (p. 40). (*D. W. Hall, Miss P. M. Davey*).

(e) *Capacitor Probe*

Investigations into the practicability of using aluminium-aluminium oxide-graphite capacitor probes for the measurement of relative humidity in tropical climates have been started. The probes are being made at the Laboratory and will be tested in controlled humidities over salt solutions at 30 C. (*G. A. Haswell, T. A. Oxley*).

(f) *Specific Heat of Paddy, Oats and their Products*

The specific heats of paddy, shelled rice, fully milled rice, oats and groats were determined at three moisture content levels using the modified Bunsen rice calorimeter constructed and used by Mr. Disney (*see Report for* 1953). (*G. A. Haswell*).

(g) *Bruchidae*

The family of beetles known as the Bruchidae are major pests of certain oilseeds and pulses. Several lines of work have been started to obtain accurate information on (a) their taxonomy, (b) their biology, and (c) their distribution.

(1) In the first instance effort has been concentrated on two main aspects of taxonomy.
Clarification of the *Callosobruchus maculatus*/*C. analis* complex, and of the synonymy of *Caryedon fuscus* the latter being at the suggestion of the British Museum (Natural History).
Bruchid beetles have been received from many Overseas territories and where possible stocks are being maintained. (*R. W. Howe, D. W. Hall, B. G. Southgate*).

(2) The beetle *Caryedon fuscus* has been cultured in the laboratory and the optimum conditions for breeding on hand-shelled and on undecorticated groundnuts determined. (*D. W. Hall, Miss P. M. Davey*).

(3) A survey of the literature on the biology of Bruchids of economic importance to stored products is being carried out. (*Miss P. M. Davey*).

(h) *Paper-lined Sacks*

The treatment of jute sacking with insecticides to minimize cross infestation of produce was referred to in the 1952/53 reports. Since certain trades such as the cocoa trade are unwilling to allow the use of insecticides near the produce the advice and collaboration of the British Jute Trade Research Association was obtained in experimenting with paper-lined jute sacks. The effect of paper lining on the penetration of jute sacking to Flour beetles (*Tribolium gastaneum*), Granary weevils (*Calandra granaria*), Cigarette beetles (*Lasioderma serricorne*), and Tobacco moth larvae (*Ephestia elutella*) has been determined by the Insecticide Section (see p. 17).

LIBRARY

The library has acquired, during the year, some 140 books, 475 reprints, 260 reports, translations, etc., and 26 additional annual report series. The holdings are now: 920 books, 7100 pamphlets, 87 annual report sets and 166 periodicals, several of these last being in duplicated form.

Eighty periodicals are now seen on regular loan. During the year 600 items have been borrowed from other libraries in response to special requests from laboratory staff, and 350 items have been lent outside the Laboratory.

Relevant articles in all periodicals received in the library are brought to the attention of the research staff concerned. Such articles, as well as all acquisitions and information from loans and abstracts, are indexed (under author and subject). The total number of items indexed during the year was 3100.

APPENDIX I

Papers Published in 1954

1. Brown, W. B. Fumigation with Methyl Bromide under Gas-Proof Sheets. *Bull. Pest Infestation Research* No. 1, 1954, vi+38 pp. 2s. 6d.

2. Coombs, C. W. and Woodroffe, G. E. *Salebius tarsalis* Casey (Col. Cryptophagidae) imported into Britain. *Ent. mon. Mag.*, 1954, **90** (1083), 186–187.

3. Disney, R. W. The Specific Heat of Some Cereal Grains. *Cereal Chem.*, 1954. **31** (3), 229–239.

4. Green, A. A. and Kane, J. The Control of Blowflies infesting Slaughter-houses. III. Large Scale Experiments at a Domestic-Refuse Depot. *Ann. appl. Biol.*, 1954, **41** (1), 165–173.

5. Hall, D. W. The Quality of Groundnuts from the Gambia with Special Reference to Insect Infestation. *Colon. Pl. Anim. Prod.*, 1954, **4** (3), 227–235.

6. Hall, D. W. and Hyde, M. B. The Modern Method of Hermetic Storage. *Trop. Agriculture, Trin.*, 1954, **31** (Apr.), 149–160.

7. Hammond, J. H. An Actograph for Small Insects. *J. sci. Instrum.*, 1954, **31** (2), 43–44.

8. Haswell, G. A. A Note on the Specific Heat of Rice, Oats and their Products. *Cereal Chem.*, 1954. **31** (4), 341–342.

9. Herford, G. V. B. Developments in Work on Pests of Stored Products. Rep. 6th Commonw. ent. Conf., 1954, 110–113, discussion 113–116.

10. Hewlett, P. S. Insecticidal Synergism with Valone. *Nature*, Lond., 1954. **173** (4394), 132.

11. Hewlett, P. S. A Microdrop Applicator and its Use for the Treatment of Certain Small Insects with Liquid Insecticide. *Ann. appl. Biol.*, 1954, **41** (1), 45–64.

12. Hyde, M. B. The Occurrence and Significance of Sub-Epidermal Fungi in Cereal Grains. *Proc. 7th int. bot. Congr., Stockholm 1950.* 1954, 206–207, summary of paper read.

13. Lewis, S. E. and Slater, E. C. Oxidative Phosphorylation in Insect Sarcosomes. *Biochem. J.*, 1954, **58** (2), 207–217.

14. Moore, B. P. The Assay of ' Pyrethrin ' and Allethrin Concentrates with 2 : 4-Dinitrophenylhydrazine. *J. Sci. Fd Agric.* 1954, **5** (10), 500–504.

15. Slater, E. C. and Lewis, S. E. Stimulation of Respiration by 2 : 4-Dinitrophenol. *Biochem. J.*, 1954, **58** (2), 337–345.

16. WINTERINGHAM, F. P. W. and HELLYER, G. C. Effects of Methyl bromide, Ethylene dibromide, and Ethylene dichloride on the Phosphorus Metabolism of *Musca domestica* L. *Biochem. J.* 1954, **58** (4), xv. (summary of paper read at 333rd Mtg. Biochem. Soc., Oct. 1954.)

17. WOODROFFE, G. E. An Additional Note on the Fauna of Birds' Nests in Britain. Bull. ent. Res., 1954. **45** (1), 135–136.

18. WOODROFFE, G. E. and SOUTHGATE, B. J. An Investigation of the Distribution and Field Habits of the Varied Carpet Beetle, *Anthrenus verbasci* (L) (Col., Dermestidae) in Britain, with Comparative Notes on *A. fuscus* Ol. and *A. museorum* (L). *Bull. ent. Res.*, 1954, **45** (3), 575–583.

APPENDIX II

Staff of the Pest Infestation Laboratory
1954

Director of Pest Infestation Research: G. V. B. Herford, O.B.E., M.Sc.

Assistant Director: E. A. Parkin, D.Sc., Ph.D., M.Sc., D.I.C.

BIOLOGY SECTION

Principal Scientific Officers: M. E. Solomon, M.Sc., R. W. Howe, B.Sc., A.R.C.S.
Senior Scientific Officers: C. W. Coombs, M.Sc., G. E. Woodroffe.
Senior Experimental Officer: A. M. Cunnington.
Experimental Officer: Mrs. G. M. Blake, B.Sc.
Assistant Experimental Officers: J. O. Bull, B.Sc., D. H. Burges, B.Sc., L. P. Lefkovitch, B.Sc., F.Z.S.
Senior Assistant (Scientific): B. J. Southgate.
Assistants (Scientific): *Miss B. E. Adamson, Miss M. Borrett, Miss J. E. Currie, Miss A. Dickson, *Miss M. C. Jackson, Miss S. M. Nightingale.

INSECTICIDE SECTION

Senior Principal Scientific Officer: E. A. Parkin, D.Sc., Ph.D., M.Sc., D.I.C.
Principal Scientific Officer: P. S. Hewlett, B.Sc.
Senior Scientific Officers: J. A. Hope, B.Sc., B. P. Moore, Ph.D., D.Phil., B.Sc.
Senior Experimental Officer: A. A. Green, M.B.E.
Scientific Officer: Mrs. P. J. Maycock, B.Sc.
Assistant Experimental Officers: G. T. Bills, B.Sc., K. G. Gostick; C. J. Lloyd; Miss E. I. C. Preston, B.Sc., *A. M. Simmonds.
Assistants (Scientific): Miss C. Belcher, Miss D. G. Blackman, D. G. H. Halstead; Miss M. J. Kane; Miss R. Phillips; P. S. Tyler†.

FUMIGANT SECTION

Principal Scientific Officer: W. Burns Brown, M.Sc., F.R.I.C., A.R.C.S., D.I.C.
Senior Experimental Officer: H. K. Heseltine.
Experimental Officers: S. G. B. Heuser, Miss E. M. Reynolds.
Assistant Experimental Officers: Miss B. D. Hole, J. D. Pearson, B.Sc.; Mrs. B. M. Reynolds, J. B. Waller.
Assistants (Scientific): Miss M. F. East, Mrs. C. E. Freeman.

BIOCHEMISTRY SECTION

Principal Scientific Officer: F. P. W. Winteringham, F.R.I.C.
Senior Scientific Officer: S. E. Lewis.
Senior Experimental Officer: A. Harrison.
Scientific Officer: R. G. Bridges, B.Sc.
Experimental Officer: K. S. Fowler, B.Sc., A.R.I.C.

Assistant Experimental Officers: Mrs. P. M. Bridges, B.Sc.; K. H. Hallowes, B.Sc.; G. C. Hellyer; J. P. Heslop, M.Sc.; Mrs. B. G. Patterson, B.Sc.; G. M. Price, B.Sc.
Assistant (Scientific): Miss A. Weatherley.

GRAIN STORAGE AND MYCOLOGY

Senior Principal Scientific Officer: T. A. Oxley, B.Sc., A.R.C.S.
Senior Scientific Officer: Miss M. B. Hyde, M.Sc.
Assistant Experimental Officers: G. Ayerst, B.Sc., ‡R. W. Disney.
Assistants (Scientific): †D. Budd; Miss M. Keeping; Miss G. Wickenden.

COLONIAL LIAISON

Colonial Liaison Officer: D. W. Hall, B.Sc. (Senior Scientific Officer).
Scientific Officer: G. A. Haswell, B.Sc., D.I.C.
Experimental Officer: Miss P. M. Davey, M.Sc.
Clerical Officer/Secretary: Miss M. M. Wood.

LIBRARY

Experimental Officers: Miss H. C. N. Turnbull, M.A., Mrs. S. G. Ayerst, B.Sc.
Assistant Experimental Officer: Mrs. C. M. Hardwick, B.Sc.
Clerical Officer: Miss B. A. Kent.

PHOTOGRAPHY

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GLASSBLOWER

Senior Assistant (Scientific): A. E. Broughton.

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14 INDUSTRIAL STAFF

[Miss P. L. Robertson, Civil Service Research Fellow.]

* Resigned in 1954.
† On National Service.
‡ Treasury Bursar.

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DEPARTMENT OF
SCIENTIFIC AND INDUSTRIAL RESEARCH

REPORT OF THE PEST INFESTATION RESEARCH BOARD

WITH THE REPORT
OF THE DIRECTOR OF
PEST INFESTATION RESEARCH

FOR THE YEAR 1955

LONDON
HER MAJESTY'S STATIONERY OFFICE
1956

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31st December, 1955

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Department of Scientific and Industrial Research,
Charles House, 5–11 Regent Street,
London, S.W.1.

* Resigned during 1955

CONTENTS

REPORT OF THE PEST INFESTATION RESEARCH BOARD FOR THE YEAR 1955

To the Lords of the Committee of the Privy Council for Scientific and Industrial Research

MAY IT PLEASE YOUR LORDSHIPS,

WE, the Pest Infestation Research Board, beg leave to present a report on our proceedings during the year 1955. The Report of the Director of Pest Infestation Research is appended.

The following members have retired from the Board during 1955: Mr. W. McA. Gracie, Prof. A. D. Peacock, and Mr. N. D. Riley. New members appointed were Prof. J. B. Cragg and Dr. J. D. Mounfield.

We have held only two meetings during the year, the summer meeting having to be cancelled on account of the railway strike.

The year under review has been marked by steady progress in all sections of the work of the Laboratory, which is now fifteen years old.

There is a widely recognized tendency, when research organizations have been in existence for a number of years, for the research programme to settle into a few well defined grooves, from which it becomes increasingly hard to escape. We conceive it to be one of our chief duties as a Research Board, continually to review the appropriate field of work on a broad basis to ensure that undue specialization along restricted channels does not occur. We are glad to report that, in our opinion, the senior staff of the Laboratory are fully alive to this danger, and we are in fact impressed not only with the wide range of problems under investigation and the general flexibility of outlook, but also with the enthusiasm which infects the whole staff.

However difficult it may prove to evaluate the scientific work of the Laboratory in financial terms, there is no doubt in our minds that it has contributed significantly to the progress that has been achieved towards the more hygienic storage and processing of foodstuffs in this country. It is exceptional today to meet a shipowner, warehouse keeper or food manufacturer who is not cognizant of and worried by the threat of infestation. Moreover, such infestation is no longer accepted as inevitable.

There is, however, no room for complacency. In Britain we are behind the United States in the standards demanded in imported foodstuffs in respect of freedom from infestation. One of the reasons for this is the necessity for British food manufacturers to import a large proportion of their raw materials, over the initial infestation of which they may have very little control. It is, therefore, encouraging to note that the Laboratory has maintained and extended its interest and influence in problems of infestation overseas, especially in the Colonies. We would draw attention to the extensive visit paid by a senior member of the Laboratory staff to the Gambia to undertake experimental work on the control of insect infestation of stored groundnuts. We would refer also to the

visit by two other senior members of the staff to Northern and Southern Rhodesia to advise on the fumigation of grain in silos, and by yet a fourth to Kenya and Uganda to advise on problems of grain storage. It is significant that all these visits were undertaken at the request and expense of the territories concerned.

We are glad to report that the Colonial Office has agreed to the formation of a Pool of stored products entomologists and chemists, to be attached to the Laboratory. Members of the Pool will be available to undertake specific investigations in Colonial territories, on completion of which they will return to the Laboratory, in readiness for the next assignment. Recruitment for the Pool has begun and we hope to be able to report, next year, that it is in operation.

We give below an outline of the main lines of work in progress at the Laboratory during 1955.

BIOLOGY

The main effort has been devoted, as before, to the investigation of the rate of development and powers of survival under different physical conditions of the more important stored product pests, both insects and mites. This work throws light on the potential distribution of the different species and is therefore of special interest to Colonial territories, where climatic extremes are frequently met. It also provides useful knowledge concerning the ability of imported species to survive the winter in temperate climates.

Many individual studies of considerable interest and practical value are also in progress. These include work on one of the Carpet beetles, *Anthrenus verbasci*, in which it has been possible to correlate the rather complicated movements of the female beetles with their reaction to odours and to light.

A study has also been made of the biology and behaviour of the Khapra beetle, *Trogoderma granarium*, in maltings. The results show that the larvae, which can remain in a resting stage for long periods in cracks in empty malt bins, are brought out of this resting stage by sudden increases in temperature, such as occur when new hot malt is shot into the bin. Laboratory experiments prove that the rate of development of *Trogoderma* is very slow in cool malt, so there would be obvious advantages in cooling the malt after kilning and before storage. The practical possibility of this is being explored.

A certain amount of attention has had to be paid to the taxonomic problems of certain groups of insects in which correct identification has been difficult in the past. The insects in question are (i) the genus *Cryptophagus*, or Fungus beetles, for which a detailed key has been prepared, (ii) certain *Bruchidae* or Bean weevils, and (iii) the Flat Grain beetles, of the genus *Laemophloeus*.

GRAIN STORAGE

Particular attention has been paid to the storage of grain under airtight conditions.

An experimental underground pit has been constructed at the Laboratory, and filled with 60 tons of heavily infested maize. Measurements of gas concentrations showed that the oxygen was rapidly used up, but the carbon dioxide concentration did not show the expected increase. Nevertheless, all the insects appear to have been killed. This confirms laboratory evidence that the insects are killed by lack of oxygen rather than by excess of carbon dioxide.

Previous experiments on the storage of damp grain in airtight metal silos have

shown that a moisture content of 23 per cent is too high and adversely effects the milling and baking properties of the grain after eighteen months storage. Tests have since been made with somewhat drier grain, of 19 per cent moisture content, from which after nine months airtight storage an acceptable loaf could be made.

Two of the three airtight silo bins now contain feeding barley with a moisture content of 19 and 17 per cent; these stocks will be tested in due course for their suitability as animal feed.

It has been possible, during 1955, to undertake more intensive work on the microbiology of hermetically stored grain. It appears that fungi are not an important cause of grain damage in airtight storage. Studies are in progress on the part played by bacterial contamination, but it is too early to derive any conclusions.

INSECTICIDES

The work of the Insecticide Section falls into three fairly well defined groups; applied work, with an immediate practical objective, longer range work, both chemical and biological, and basic research.

Applied work has included three major investigations, namely a study undertaken by a senior member of the staff on the infestation of harvested groundnuts in the Gambia, where the losses have been so great as to affect the economy of that territory. Three months intensive survey and experimentation on the spot, coupled with examination of a large number of samples sent back to the Laboratory, have made it possible to make practical recommendations for insect control which, it is hoped, will result in a very marked reduction in infestation and consequent loss.

Work has continued during the year on the evaluation of different insecticidal methods for the control of the Cocoa moth, *Ephestia elutella*, in London warehouses. Similar work in 1954 had suggested that a considerable simplification of the current recommendations could be achieved without loss of efficiency, and the experiments undertaken this year were designed to confirm the earlier conclusions. The conditions of test were rather more rigorous than previously, due partly to the poor construction of the warehouse in which the experiments were undertaken. Although a good measure of control was achieved by all methods tested, it is probable that for commercial practice a slightly more generous insecticidal specification will be recommended than that used in the experiments. Even so, it would represent a marked reduction in the cost of materials and in labour.

A full scale attack has been made in 1955 on an infestation by the tropical ant, *Monomorium pharaonis*, of a very large sanatorium. One ward of this hospital had been successfully treated in 1954, and the work this year was planned to investigate the possibility of the total eradication of the ants over the whole building in one concentrated effort. It appears to have been completely successful.

The many other smaller practical investigations include tests of the penetrability of paper sacks by insects, the disinfestation of empty bags by insecticidal dusts, the use of insecticidal resins to prevent living insects being carried about in tarpaulins, and the insecticidal properties of a local West African diatomite.

Longer range work, largely continued from last year, is represented by the study of the toxicity of certain insecticides, pyrethrum, benzene hexachloride

and malathion, to a range of stored product insects, and by work on the chemical assay of pyrethrum.

Basic research, largely continued from previous years, includes studies of the respiration of insects treated with insecticides, measurement of the retention of spray by different species of insects, statistical aspects of insecticidal action, and the chemical synthesis of contact insecticides.

FUMIGANTS

Work on fumigants has been largely practical in nature. Detailed tests have been made in a very large silo installation in Africa, equipped, following plans submitted by the Laboratory, for the fumigation of the silo bins by circulation.

The Laboratory also assisted in the second fumigation with methyl bromide of H.M.S. *Victory*, in an attempt to eradicate the Death Watch beetle by which she is infested.

In 1954 it had been shown that, contrary to previous opinion, flour could be fumigated with methyl bromide without consequent tainting. Accordingly, the possibility of fumigating large stacks of imported bagged flour under gas proof sheets has been investigated. Results showed that the distribution of fumigant throughout the stack was unsatisfactory under normal methods of application, and it is clear that modifications will have to be made before success can be assured. Further tests are planned.

Tests, undertaken in conjunction with the Infestation Control Division of the Ministry of Agriculture, Fisheries and Food, have been made of a process using phosphine as a fumigant for bulk grain. This technique is widely used in Germany and certain other countries.

A considerable amount of time has been spent on the testing of different instruments for the analysis of halogenated hydrocarbons in air, both for field and laboratory use.

The study of the toxicity of different fumigants to a range of stored food insects has been continued.

BIOCHEMISTRY

Biochemical work has been directed along two main lines; the detailed investigation of the chemical reaction of insecticidal materials with different foodstuffs, and basic research into the mode of action of insecticides.

In the first category, it has been shown that the sortion of ethylene dibromide by wheat is largely physical, and desorption on aeration is slow. If wheat is heated before it has been completely aerated, about one-third of the residue is decomposed to ethylene glycol, and the remainder is volatilized.

Work is in progress on the nature of the residues formed on cheese and on wheat when treated with lindane (gamma benzene hexachloride).

Work on the mode of action of insecticides has included a study of the phosphorus metabolism of living houseflies, and the effect on this metabolism of treatment with insecticides such as DDT. This work has been extended to include a study of non-phosphorus-containing metabolites. In both of these types of investigation the insect rather than the insecticide is "labelled", with radioactive phosphorus and radioactive carbon, respectively.

Pyrethrum, and the closely similar synthetic insecticide, allethrin, both possess the power to paralyze insects rapidly, and their effectiveness can be increased by the addition of " synergists ". It has been shown, by the use of

allethrin labelled with radioactive carbon, that the insecticide is decomposed in the insect tissue, and that certain synergists are able to prevent this decomposition. This may be suggestive of the mode of action of synergists in general.

The biochemistry of insect metabolism is still a relatively unexplored field, and it is necessary to study these processes in the normal insect before one can appreciate the disturbances caused by insecticides. Basic research is therefore in progress in this field, and includes work on acetylcholine in insect nerve tissue, and on the metabolism of insect flight muscle.

In conclusion the Board has been particularly glad to learn that it will be possible to provide for some increase and improvement in laboratory accommodation during the forthcoming year.

F. R. HORNE,
Chairman.

February, 1956

REPORT OF THE DIRECTOR OF PEST INFESTATION RESEARCH FOR THE YEAR 1955

GENERAL

The year 1955 has been marked by good progress in all sections of the work of the Laboratory. As will be seen in the detailed report which follows, a number of investigations have been completed and new ones started.

A small expansion of the scientific staff has been authorized as part of the Department's five-year plan, and it is expected that after much delay work will soon be started on the new Insecticide laboratory, the need for which is being increasingly felt.

An economist, attached to the Intelligence Division of the Department, is engaged on an investigation of the magnitude and type of loss associated with the infestation of stored foodstuffs in this country. As a first approach, a study is being made of the losses sustained by farmers. The work has been undertaken with full realization of its inherent difficulties, not the least of which lies in the lack of comparable data for the pre-war period, when there was no organized work on the prevention and control of stored products infestation.

Mr. Ayerst, who has recently started work on the microbiology of foods in storage, spent some time in the microbiological section at the Chemical Research Laboratory, to improve his knowledge of bacteriological techniques.

Approval has been given by the Colonial Office to the formation of a Pool of stored products entomologists and chemists, referred to in previous reports. It is intended that these men, who would be home-based, shall be available to investigate specific problems in Colonial territories, especially in those Colonies which are not able to engage permanent staff for this type of work. It is proposed that the members of the Pool should work at the Pest Infestation Laboratory in the intervals between their engagements overseas.

Several senior members of the Laboratory staff have been overseas during 1955.

The Director visited West Africa and represented the Colonial Office as chairman of a committee set up to review annually the work of the West African Stored Products Research Unit. He also visited the Gambia.

Mr. Oxley visited Kenya and Uganda, at the request of these countries, to advise on grain storage problems.

Mr. Burns Brown and Mr. Heseltine visited Southern Rhodesia, by request, to test and make recommendations for the operation of a new grain silo fitted for the circulatory fumigation of grain.

Mr. Green spent three months in the Gambia, at the request of the local Government, surveying the infestation of harvested groundnuts and carrying out experiments on control methods.

Mr. Haswell (Assistant to the Colonial Liaison Officer) visited East, Central and South Africa, reviewing progress in infestation control.

Dr. Parkin (Assistant Director) attended international committee meetings on

techniques for the assessment of mothproofing efficiency. The meetings were held in Paris and in Munich.

Mr. Oxley and Miss Hyde presented a paper at the 3rd International Bread Congress in Hamburg.

Mr. Winteringham, Mr. Lewis and Mr. Fowler attended the 3rd International Congress of Biochemistry in Brussels, where Mr. Winteringham read a paper. He afterwards visited research institutions in Holland.

The Director is Chairman of the Stored Products Research Sub-Committee of the Committee for Colonial Agricultural Forestry and Animal Health Research, of which he is a member. He is also a member of the Colonial Pesticides Committee.

The Assistant Director is Chairman of the Larval Test Sub-committee of the Moth and Dermestid Beetle Proofing Committee, and is a member of the Pyrethrum Research Committee.

BIOLOGY

The current work of the Biology Section follows a set of inter-related themes:

Rates of development, reproduction and net increase
Tolerance of extremes of temperature and humidity
Analysis of habits by behaviour studies
Sources of infestations
World distribution of various species
Systematic revision, description of new species, identification of material

Many of the items reported in the following pages deal with work continued from earlier years. The new projects include the study of effects of fluctuating temperatures on the Australian Spider beetle *Ptinus tectus*. This development from experiments under constant conditions will probably continue on an increasing scale, and a second cabinet to produce controlled diurnal cycles of temperature is being constructed.

Another new development is the enquiry into the quantity of insects that can be reared on a given food supply. This arises naturally from the normal Insectary procedure.

In the latter part of the year, an examination of all earlier results of work at this laboratory on the speed of development of beetles in relation to temperature was begun, with the aim of finding what general conclusions could be drawn regarding the shape of the temperature-development curves.

Findings of great general interest to biologists have arisen from the observations on *Ptinus latro*, reported on a later page.

The work of the Section has as usual depended to a considerable extent on the co-operation and help of officers of the Infestation Control Division Ministry of Agriculture, Fisheries and Food, and of the Food Infestation Control Department of Agriculture for Scotland. Indispensable assistance has also been rendered by Museums who have loaned valuable specimens, and by other institutions and individuals in Britain and abroad.

LIFE HISTORIES AND PHYSICAL LIMITS OF VARIOUS BEETLES

The study of the rates of development and mortality of beetles from stored products has been extended to several additional species this year. Such work has been almost completed for *Laemophloeus ugandae*, and considerable progress has

been made with four species of Bruchids (Bean weevils). Long-term experiments with the Spider beetles *Ptinus pusillus* and *Ptinus hirtellus*, are still in progress. Some experiments to supplement the work of earlier years have been carried out on the Rust-red Flour beetle *Tribolium castaneum*, the Cigarette beetle, *Lasioderma serricorne* and *Ptinus tectus*. In addition to these items, which are dealt with below, work had commenced on the Confused Flour beetle, *Tribolium confusum*, *Laemophloeus turcicus*, *L. spartii*, and one of the Bean weevils, *Zabrotes (Spermophagus) subfasciatus*.

Development and physical limits of Laemophloeus ugandae

This newly described species from maize and groundnuts in Uganda and W. Africa is much more sensitive to humidity differences than are most stored products beetles. At. 30°C, which is near to the optimum temperature, development is appreciably slower at 70 per cent than at 90 per cent relative humidity; at 22·5°C it takes nearly twice as long at the lower humidity as at the higher. At a relative humidity as low as 50 per cent, only a few completed the life cycle, over the temperature range 25°–32·5°C. Development is not completed below 17·5° or above 35°C. (*L. P. Lefkovitch*).

Development and physical limits of four Bruchids (*Bean weevils*)

Although this work is incomplete, there are indications of differences in their temperature and humidity requirements. All are being reared on dried peas, except *Acanthoscelides obtectus*, which is reared on haricot beans. At 35°C, *Callosobruchus analis* has completed its life cycle, while only a few *Callosobruchus maculatus* and no *Callosobruchus chinensis* or *A. obtectus* have yet done so. Only *A. obtectus* has been found to complete the life cycle at 17·5°C, but all except *C. analis* have done so at 20°C. The rates of development and mortality in immature *A. obtectus* and *C. chinensis* are little affected by humidity differences over the range 50 to 90 per cent relative humidity. *C. maculatus* does best in the upper part of this humidity range, while *C. analis* suffers a high mortality under such conditions. The optimum temperature for all species is about 30° to 32·5°C.; *C. analis* develops more slowly than the other three. (*R. W. Howe*, *Miss J. E. Currie*).

Development of Tribolium castaneum *under cool conditions*

To supplement the work of previous years, the effects of moderately low temperature, 20°C and below, on the developmental stages of the Rust-red Flour beetle are being examined. Exposure to 15°C for a month in the prepupal stage gives rise to abnormalities. If pupae are exposed to 17·5°C the newly formed adults sometimes fail to slough the pupal skin. Exposure to 15°C for a month leads to the formation of adults which cannot fold their hind wings; but they can mate and produce a few fertile eggs. (*R. W. Howe*).

Limits of dryness for the Cigarette beetle

Life history studies of *Lasioderma serricorne* in the laboratory showed that this beetle could breed in much drier conditions than had been previously supposed. Even so there are many areas of the world which are, at some time of the year, too dry for active breeding of this species. The stage most easily killed by dryness is the very young larva. The lower humidity limits for this stage are about 45 per cent relative humidity at 20°C falling to 25 per cent as the temperature

rises to 30°C and rising again to 30 per cent at 35°C. When half-grown larvae were exposed in culture to relative humidities some 5 to 10 per cent below these limits there were living adults or pupae in every culture three months later. It appears that the low humidity retards growth, so that in a dry period of three months' duration a population of varied ages would not all pass through the susceptible young larval stage. (*R. W. Howe, Miss J. E. Currie*).

Some fluctuating temperature conditions unfavourable to Ptinus tectus

Work at constant temperature with the Australian Spider beetle was inadequate to show whether this species could be expected to establish itself in certain semi-tropical countries in which the diurnal cycle of temperature varies from above the maximum for this species (28·5°C) to below its optimum (25°C). The incubator referred to in *Pest Infestation Research*, 1953, p. 7 (and Plate I in the present issue) was used to give controlled diurnal cycles varying from 26° to 31°C, 23° to 34°C, 21° to 33°C, and 23° to 31°C. In none of these was the beetle able to complete its developmental cycle, although in the latter two the pupal stage was reached. It was concluded that this species could not become established in certain regions previously classed as "probably unsuitable" (the hotter areas stippled in the map figures on p. 6 of *Pest Infestation Research*, 1952). (*R. W. Howe*).

LIFE HISTORIES AND PHYSICAL LIMITS OF CERTAIN MITES

Rate of increase of the Flour mite

A start has been made this year on the final calculations from experiments to determine the rate of increase of *Tyroglyphus farinae* under the various physical conditions tolerated by this pest. (*M. E. Solomon, A. M. Cunnington*).

Resistance of eggs of the Flour mite to low humidity

In continuation of the work reported in 1953, experiments on *Tyroglyphus farinae* have been carried out at 5°C. About one per cent of the eggs survived 20–25 days at a relative humidity of 20 per cent, or 40 days at 40 per cent relative humidity. Less than 10 per cent survived 25 days at 30 per cent or 40 days at 60 per cent relative humidity. (*A. M. Cunnington, Miss A. M. Dickson*).

Life history of Glycyphagus destructor

Experiments started last year to give information on the life history and habits of the mite *Glycyphagus destructor* at 25°C have been completed. As at 20°C (cf. *Pest Infestation Research*, 1954), it was found that *G. destructor* took longer to develop than *Tyroglyphus farinae* over the same range of relative humidity (i.e. 70–90 per cent) and laid considerably fewer eggs. At 25°C and 70 per cent relative humidity there was a considerable increase in the time taken by *G. destructor* to develop from egg to adult and a marked decrease in its egg-laying capacity relative both to its performance at higher relative humidities and also to that of *T. farinae*. In addition the length of life of the adult was much reduced.

Experiments are also in progress at 5° and 10°C. At the latter temperature results show that *G. destructor* continues to develop more slowly than *T. farinae* over the same range of relative humidity (70–90 per cent). At 70 per cent relative humidity, however, the mortality among the juvenile stages was extremely high and only one adult developed from 150 eggs.

These results suggest that the active stages of *G. destructor* are less tolerant of low humidity than those of *T. farinae*. (*A. M. Cunnington, Miss A. M. Dickson*).

Formation of the hypopus stage in Glycyphagus destructor

The experiments commenced last year to secure information on the conditions affecting the formation of the very hardy hypopus stage in *Glycyphagus destructor* have been continued. Experiments to determine the effect of crowding have shown that, while more hypopi are found among the denser populations, the numbers produced are so small that crowding cannot be considered a primary factor affecting hypopus formation in this species. Experiments were also set up to test the effect of starving emerging protonymphs; no hypopi were produced. Detailed experiments to test the effect of relative humidity at different temperatures on hypopus formation are in progress. (*A. M. Cunnington*).

Resistance of Glycyphagus destructor *hypopi to drying*

It has long been known that the hypopus stage of *Glycyphagus destructor* is extremely resistant to dry conditions but exact information is lacking. A number of experiments have therefore been set up at 20°C, and will be repeated at other temperatures to secure information on this point. After nearly six months at 10 per cent relative humidity some hypopi have been found to survive and to continue their development when removed to more favourable conditions. (*A. M. Cunnington, Miss A. M. Dickson*).

Life history of Cheyletus Eruditus

This predatory mite has been bred at 20°C and 75 per cent relative humidity. Each mite was kept in a separate small cell and supplied with prey in the form of Flour mites, *Tyroglyphus farinae*, maintained at an approximately constant level. A complete life and fertility table has been drawn up, showing also the numbers of prey consumed. The *C. eruditus*, which as usual were all females, developed to the adult stage in about 3 weeks, and during this period consumed about 11 to 14 *T. farinae* per week. The adults consumed 11 to 28 prey per week in the first 7 weeks of their maturity and produced eggs parthenogenetically at rates varying from 15 to 24 per week. Not excluding those which died young, an "average" *C. eruditus* under these conditions would live 11 weeks, eat 144 *T. farinae*, and lay 110 eggs.

This work, to be continued on the present small scale under various conditions, will provide background for experiments and calculations on the efficiency of *C. eruditus* in controlling populations of *T. farinae*. (*M. E. Solomon, Miss R. Borrett*).

BIOLOGY AND BEHAVIOUR OF THE KHAPRA BEETLE

Studies in malt stores

New malt at a temperature optimal for the breeding of *Trogoderma granarium* was stored in a large silo bin at a malting infested with this species. Larvae penetrated to the centre and rapid breeding took place, which caused the malt to heat. As a result living larvae were driven outwards and only dead adults remained near the centre. Without the heat produced by the insects, the natural cooling of the malt would probably have prevented heavy infestation. It is believed that slight cooling of such bulks of malt when the malt enters the store

would inhibit population increase sufficiently to prevent insect heating, and it is hoped to arrange some cooling trials.

In hot-air chambers the malt nearest the kiln is kept hot and the rest cools. In one chamber the amount of malt cool enough to prevent Khapra increase was found to vary with weather conditions and the season of the year. The temperature of the malt nearest the kiln fluctuated with the temperature cycle of the kiln and frequently became too hot for the insects.

At another malting the infestation in the whole malt storage section was greatly reduced by avoiding the use of one small store prone to very severe infestation. The population left in the fabric of the building at the end of the year was halved, and consisted mainly of larvae surviving from the previous year.

A grain sampling spear for use with a domestic vacuum cleaner has been developed. Samples of unlimited size can be obtained from depths as great as 25 ft., and can be taken from positions inaccessible to other spears. The amount of dust and debris in samples was no greater than in samples taken with a conventional type of spear.

Laboratory study of development

Normally a population of this species contains two types of larvae, which can be distinguished as long-lived and short-lived (*Pest Infestation Research*, 1954, pp. 9 and 10). Further study of the resting phase in the life of the long-lived larvae has led to the conclusion that this phase can be classed as a diapause: that is, it occurs at temperatures normally favourable to development. Since the short-lived larvae omit this phase, it must be classed as a facultative type of diapause. Also, since this phase is shorter in some larvae than in others and since it can usually be terminated by appropriate changes in external conditions, it is a weak diapause.

The onset of diapause is controlled by temperature and food deterioration and it is also influenced by hereditary variations. It was induced in some or all of the larvae by accumulation of frass or by a staling of the food itself caused by infestation. It was more frequent at lower temperatures than at higher temperatures within the normal range of the species.

The termination of the diapause by an increase in temperature has now been studied in greater detail. Large abrupt increases and high temperatures were most effective. Neither temperatures varying diurnally between 21° and 35°C, nor abrupt changes in humidity were able to bring it to an end. The diapause enables the insect to survive in empty stores and it is readily broken when the stores are filled with new hot malt, so that the insect quickly takes advantage of a return to favourable conditions.

Experiments on vertical movements

Experiments on the vertical movement of the species in columns of wheat, four feet long and four inches in diameter, have been carried out with both adults and larvae. Female adults placed near the surface move less than males, which in turn moved less than larvae. Young larvae moved downwards into the grain more than older larvae freshly emerged from diapause. (*H. D. Burges*).

BEHAVIOUR OF THE VARIED CARPET BEETLE

Reactions to humidity

A programme of experiments on the reactions of *Anthrenus verbasci* to humidity, started in 1951, has now been completed, and an account prepared for

publication. The apparatus used was the alternative chamber of Gunn and Kennedy, as modified by Wigglesworth. Four atmospheres of 30, 50, 70 and 90 per cent relative humidity were tested in pairs, giving six combinations. Adults and young larvae, but not fully-grown larvae, exhibited a response to humidity and showed a preference for the lower end of the humidity range. The power of the insects to discriminate between any two humidities was dependent upon the difference between the humidities compared.

Reactions to light

The study of the response of adults of *A. verbasci* to light (cf. *Pest Infestation*, 1951, p. 10, 1953, p. 10 and 1954, p. 10) has also been concluded and an account prepared for publication.

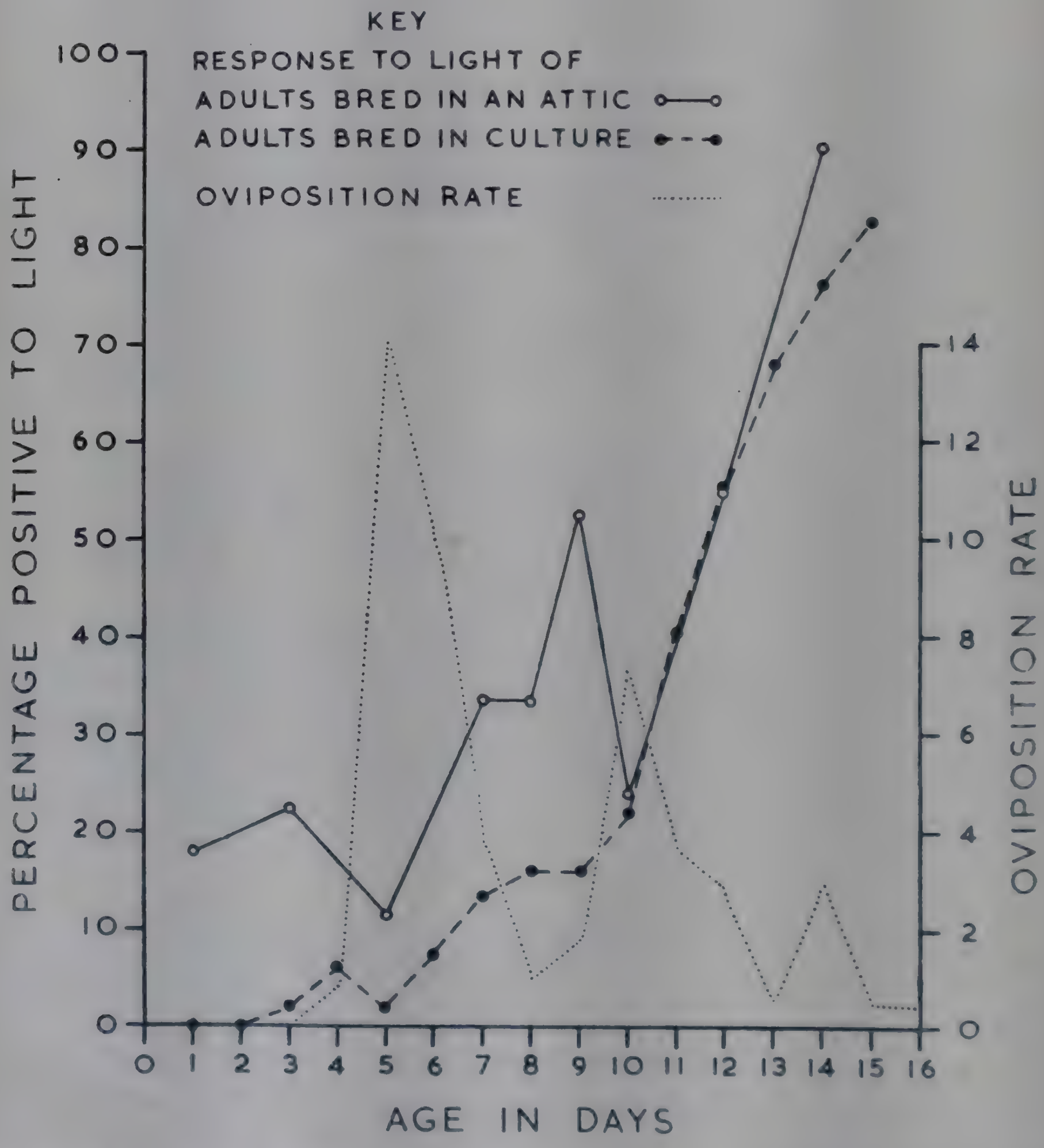

FIGURE 1. *The correlation between response to light, oviposition rate and age of adult female carpet beetles* (Anthrenus verbasci)

The percentage of fertilized females attracted to light increases with age from about 10 per cent at 0–1 days old to about 90 per cent at 14–15 days old. Fertilized females show a tendency to move away from light during peak periods of oviposition so that when the percentage of females positive to light is plotted against age there is shown to be a negative correlation with the oviposition curve. There are indications that this correlation between response to light and oviposition is most strongly exhibited by females which have been reared and kept during adult life under "natural" fluctuating conditions such as are found in attics (Fig. 1).

The response to light of virgin males and females, kept in an attic with diurnal illumination, was tested daily for the first fifteen days of adult life. Virgin females became positive to light at a much earlier age than mated females; 90 per cent were positive to light by the 5th day. The males became positive to light about the 9th to 13th day.

Behaviour cycle of adult beetles

In the light of these results the behaviour pattern of adult beetles can to some extent be explained. It was shown earlier (*Pest Infestation Research*, 1952, p.12) that adult beetles are attracted by the odours of birds' nests. Most of the eggs are laid in nests in the eaves of houses and in the autumn when the larvae are full grown a certain percentage wander from the nest and infest the rooms of the house. As a result some adults emerge in isolated places and the positive response to light of virgin females will take them, if conditions permit, to the light and open air. Attraction to the odours of certain flowers (*Pest Infestation Research*, 1951, p. 10) will cause aggregations on flower heads where mating has frequently been observed. The adults derived from the larvae which remain in the nests will fly out to congregate on flowers if they are not fertilized, but if mating occurs during the first day or two the negative response to light of the fertilized females will cause them to remain in the nest until at least the first batch of eggs has been laid. Some fertilized females respond positively to light between peak periods of oviposition and these will perhaps fly off to flowers during this interval, whilst those which respond negatively to light until the twelfth day will remain until the second batch of eggs has been laid.

Correlation of light reaction and oviposition, together with the positive response to certain flower odours and bird nest material, ensures the continuance of old infestations and the starting of new ones. (*Mrs. G. M. Blake*, *Miss R. Borrett*).

YIELD OF INSECTS FROM A GIVEN FOOD SUPPLY

The chief function of the Insectaries is to maintain stocks of insects for use in experimental work at the Laboratory. As a development from this routine, a programme of experiments has been commenced with the aid of determining, for a few species, the maximum yield or crop of insects that can be reared on a given quantity of foodstuff. The amount of the crop is likely to be influenced by temperature and humidity, by crowding effects, wastage due to mortality, or in many species by cannibalism, as well as by the nature of the foodstuff; such factors will also influence the rate at which the crop of insects is produced. Some of these points may be investigated. Experiments to date have been concerned with the Cigarette beetle, *Lasioderma serricorne*, on "wheatfeed", a grade of miller's offals which produces about 0·23 g of this insect per g of foodstuff.

Information from such experiments should throw light on the amounts of damage which can be caused by populations of pests and on the food supply relationships of populations living on residues of produce in the fabric of storage buildings. The results should also provide instructive comparisons with rates of increase calculated from laboratory rearings without crowding. (*J. O. Bull, M. E. Solomon*).

RESIDUAL POPULATIONS OF INSECTS

Concealed populations in a flour mill

A visit was made to a flour mill from which the machinery was being removed. Samples were taken chiefly from those parts of the distributor system not normally accessible for cleaning.

Live insects found, in order of abundance, were the Mediterranean Flour moth (*Ephestia kühniella*), the White-shouldered House moth (*Endrosis sarcitrella*), the Cadelle (*Tenebroides mauritanicus*), the Australian Flour beetle (*Ptinus tectus*) and the Grain weevil (*Calandra granaria*). Very few mites were found. The number of insects in the samples was not very great. The distribution of the species in the mill tended to be sporadic except for *E. kühniella* which was general. *E. sarcitrella* was found in large numbers in an elevator boot (200 larvae from one foot length) and very rarely elsewhere; of 42 *T. mauritanicus* larvae found, 41 were associated with roller mills; the *C. granaria* were all in samples containing wheat from brushing drums. The densest population found was connected with a plansifter: from the nest of 12 sieves, 90 *E. kühniella* larvae were collected and in 2 feet of a spout leading from the plansifter over 1000 larvae were taken. (*C. W. Coombs*).

Farm survey

The study of food residues and of natural reservoirs of stored products pests such as birds' nests as sources of pests upon a farm has been suspended while the possibility of automatic extraction of insects and mites from samples is being explored.

A modified Tullgren apparatus, which has been designed and constructed in the Laboratory workshop, is capable of handling twelve samples simultaneously (Plate II). The effect of modifying the power of the electric bulbs and the setting of the apparatus upon the temperature and humidity gradients in the samples is being tested with a view to finding the optimum conditions for extraction of insects and mites from grain and other media likely to be encountered in the field. (*G. E. Woodroffe, C. W. Coombs*).

Study of population changes in grain

Earlier studies of the insect population of granary residues revealed certain trends of population change. The condition and composition of the food material could be associated with the dominance of certain species and as the conditions changed, due partly to the activity of the insects themselves, so the composition of the fauna changed also. This succession of dominant insects connected with changing conditions is now being investigated in two experiments. In a small scale experiment known numbers of pest insects have been introduced into two glass tanks containing sterilized wheat, housed in an outbuilding. Temperature and humidity readings are being kept and samples from the tanks are being taken at regular intervals for examination. In the second experiment, which is on

a much larger scale, insects have been introduced into about a ton of grain stored behind bulkheads on the concrete floor of an outbuilding. Six resistance thermometers record temperatures in different parts of the bulk. Sampling will be carried out to follow population changes associated with changes in grain condition, and to give information concerning insect distribution. Insect movements will be studied by release and recapture of marked beetles. (*G. E. Woodroffe, C. W. Coombs*).

Effect of floor cracks on the oviposition rate of the Grain weevil

In an unstocked granary many of the residual grains may lie in cracks in the floor. Experiments have shown that the oviposition rate of the Grain weevil (*Calandra granaria*) is higher upon grains held in cracks than upon grains lying loosely on the floor. Thus the presence of cracks, besides causing more grains to be left behind when the storage space is swept, may also increase the rate of oviposition of the *C. granaria* on these grains. (*C. W. Coombs*).

MITE POPULATIONS IN THE FIELD AS A SOURCE OF INFESTATION

At the end of the wet summer of 1954 a number of cases were reported of heavy mite infestations appearing within a few weeks in freshly harvested grain. The cases were sufficiently numerous to suggest that the grain was already infested when it was brought in from the field. Point was lent to this view by the collection on three different farms in Lincolnshire of heavily infested grain samples from new grain dryers in use for the first time.

That stored product species of tyroglyphoid mites occur in agricultural land is suggested by the records of early acarologists such as A. D. Michael in England and A. C. Oudemans in Europe. More recently, Russian workers have studied them in the soil in relation to cereal crops. Nevertheless, field and store records of tyroglyphoid infestations kept for a number of years contain very few instances of stored product species from field habitats.

In 1947 Tyroglyphus farinae was recorded in New Zealand from grass and soil brought into the laboratory for use in insect cages. Here it was associated with a species known to occur out of doors. In 1954 *Tyroglyphus* and *Tyrophagus* were obtained from hay, and in August of this year Mr. J. C. Dealey found a heavy infestation in a haystack out in a field about one mile from any farm building. This summer also Miss P. Piercey, of this Department, collected active stages of *T. farinae* from grain being passed through a combine harvester, and found a hypopus in wheat chaff left in a field from the previous season.

It seems clear that stored product mites may occur in the field, but the importance of the part played by these field populations in giving rise to store infestations such as those found in recently harvested grain in 1954 is only likely to be demonstrated by a special investigation. (*Miss P. L. Robertson*).

REPRODUCTION AND SYSTEMATIC STATUS OF *PTINUS LATRO*

The study of this species of Spider beetle has been continued throughout this year and certain unusual features of its life history have been investigated. A permanent culture has been established and several generations have been bred. It is now clear that *P. latro* females will lay viable eggs only after mating with *P. hirtellus* males; the progeny are all *latro* females.

The production of only one sex indicates that reproduction is parthenogenetic, i.e. that eggs develop without being fertilized in the strict genetic sense, but the

necessity for mating suggests that some sort of pseudo-fertilization occurs. Eggs laid by unmated females do not develop, so something more than a simple mechanical stimulus to oviposition must be involved. Cytological aspects of the problem are being investigated by Dr. A. R. Sanderson of the University of St. Andrews, Dundee.

So far, the nomenclatorial position has not been finally settled, but it is clear that *latro* and *hirtellus* must be regarded as races of one polymorphic species. A description of Fabricius' type of *latro*, supplied by Dr. Tuxen, of the Copenhagen Museum, suggests that some confusion has occurred, and a visit to Copenhagen has been arranged to clear the matter up. (*G. E. Woodroffe*, *B. P. Moore*).

SYSTEMATICS AND DISTRIBUTION OF VARIOUS PESTS

Taxonomy of Cryptophagus

The study of American species of Fungus beetles of the genus *Cryptophagus*, begun last year, has continued with the loan of further American collections. The U.S. National Museum has loaned its collection of these beetles, including some highly valued and irreplaceable type material, the study of which is essential for a thorough revision of the species occurring in America. This has made possible the solution of many of the major taxonomic problems in the genus. The work will be concluded when the final consignment of material arrives. (*G. E. Woodruffe*, *C. W. Coombs*).

Taxonomy and distribution of Bruchids (*Bean weevils*)

The comparison of *Callosobruchus analis* and *C. maculatus* has been completed. The description of a new species of *Callosobruchus* from Bambarra groundnuts is in progress. (*B. J. Southgate*, *R. W. Howe*.)

The records of identifications of Bruchids by the Commonwealth Institute of Entomology are being examined for information on the distribution of the species. (*B. J. Southgate*).

Distribution of species of Laemophloeus

Identification of *Laemophloeus* (*Cryptolestes*) species for Infestation Control Division, Ministry of Agriculture, Fisheries and Food, including specimens collected by Dr. J. A. Freeman, of that Division, in North and South America and the Mediterranean region, has continued. *L. turcicus* was identified from flour mills in the U.S.A., Argentina, Uruguay, Algeria, Morocco, Tunisia, Greece and Turkey, and from maize in the U.S.A. *L. spartii* was also identified from flour mills in Morocco, Greece, and Turkey. (*R. W. Howe*, *L. P. Lefkovitch*).

Variation in cheese mites

During the past year attention was concentrated on bringing together results of the study of variation in *Tyrophagus*, the most important genus attacking cheese. Further museum material—that in the Vitzthum collection, Munich—was borrowed and illustrations prepared for comparison with the species already recognized. As a background to the research on *Tyrophagus* similar studies on mite genera of importance to agriculture, medicine and veterinary science were reviewed.

The work on *Tyrophagus* was carried out as a basis for ecological investigations of cheese store populations, and was needed to clear up confusion concerning the identification of forms occurring in them. (*Miss P. L. Robertson*).

Collections of mite and insect pests of stored products

A collection of mites mounted on microscope slides has been built up over a number of years. It contains samples from stored food materials, series for the study of variation and material reared in the laboratory under controlled conditions. The collection now contains approximately 2500 slides, which are being rearranged and indexed so that they may be more readily available for reference. Preparations were made in the gum chloral mountant, Berlese's Fluid, which has been criticized for a tendency to crystallize and to overclear. Swan's modification of the formula (*Bull. ent. Res.* **27**, 389) was used, and it is interesting to record that after twelve to fourteen years slides are in reasonably good condition and without crystallization. The difficulty of obtaining clear definition of minute structure has been overcome by the use of phase contrast illumination. (*Miss P. L. Robertson*, *Miss M. Keeping*.)

The laboratory reference collection of stored products insects is being overhauled. (*B. J. Southgate*).

COBALT PAPERS FOR MEASUREMENT OF HUMIDITY

Tissue paper impregnated with cobalt thiocyanate, and permanent colour standards for use in the measurement of humidity with this paper, are expected to become generally available in 1956. Checks on variation in the impregnated paper, estimates of temperature effects, and other tests have been completed during the year. This method is particularly useful for measuring humidity in small or relatively inaccessible spaces such as in crevices, or in the air-spaces of stored materials, or in the small containers used for insects in life-history experiments. It has a more general utility whenever an approximate measure of humidity is sufficient. (*M. E. Solomon*).

GRAIN STORAGE AND MICROBIOLOGY

The most important work of the section continues to be the study of the hermetic storage of grain. The main changes in this work have been (*a*) increased attention to changes in oxygen concentration, and (*b*) practical work on an experimental pit designed for long term storage of grain and control of insect populations. Microbiological work is now much better established and has been extended to cover the study of bacteria on grain under conditions of hermetic storage. Studies of some physical properties of grain have continued and will be reported in future years. The rapid moisture tester for grain referred to in earlier reports is expected to be in full commercial production by the time this report is published. A considerable amount of work has been required during the year in order to establish a final calibration for this instrument which is now suitable for wheat, oats, barley, rye and maize. A separate calibration for paddy rice and milled rice has been prepared.

UNDERGROUND STORAGE OF GRAIN

For several years this Laboratory has been advocating that experiments on "underground" storage of grain, on the South American pattern, should be carried out in British colonial territories. Suggestions for constructing experimental pits were sent to a number of territories whose climates were judged to be suitable. In due course, three experimental pits were constructed in Tanganyika,

one in Nyasaland, and one (in Equatoria province) in the Sudan. The Laboratory made considerable efforts to ensure that a full range of scientific observations was made on these experimental pits, but in the event, although many measurements were made by the Government entomologists of the territories concerned, the results obtained were meagre. (See *Pest Infestation Research*, 1953 and 1954, Colonial Liaison section.) This was largely because the pits were from the start used as commercial storage places, scientific equipment was barely adequate and the scientific staff available were very busy on other commitments. Nevertheless, it was established that the process of underground storage is commercially very successful.

It was concluded that a proper scientific study of this very valuable form of long-term storage could only be made by direct experimentation at this Laboratory. For this purpose it was necessary to construct a pilot scale grain storage pit at an accessible point in this country. Unfortunately the site of Laboratory in Slough is particularly unsuitable for construction of grain storage pits because the water table is frequently within a few feet of ground level. In spite of this it was felt that the difficulties of working away from the Laboratory, and the inconvenience of having to secure another site, justified the extra cost of construction in the Laboratory grounds, although this necessitated using a complete "tanking" procedure.

The pit was made as small as possible without reducing the depth, or minimum width, below those which had been found desirable in tropical practice. This was achieved by making the pit square in plan, each side being approximately equal to the width of the African experimental pits. A special design was made by Building Research Station of this Department (see Fig. 2) so as to minimize

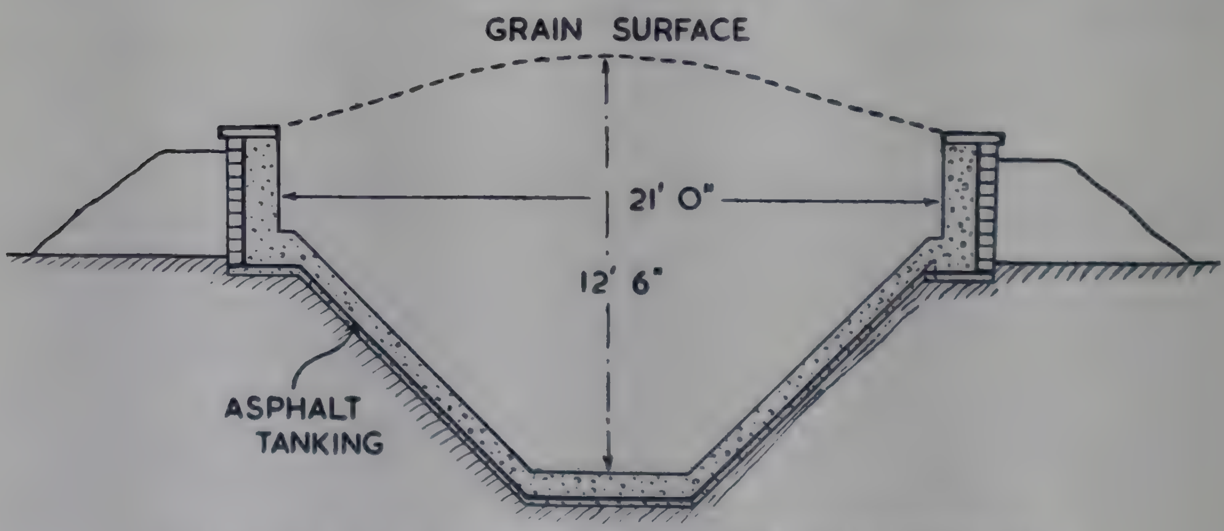

FIGURE 2. *Section of experimental grain storage pit*

the amount of excavation needed below the water table. This design has proved very satisfactory and formed the basis for an experimental pit later proposed by this Laboratory to the Government of Singapore. The internal width is 21 feet and the depth 10 feet 6 inches. The capacity, including grain heaped above the level of the top of the walls to a depth of two feet, is 3130 cubic feet, or approximately 62 tons.

Yellow American maize was obtained from an ordinary commercial source and stored in sacks and bulk for two to three weeks before the pit was to be filled. This maize contained a light infestation of *Tribolium* sp. and other insects

but in order to ensure the heavy infestation required for experimental purposes a very large number of *Calandra oryzae* were bred from insectary stock during the six weeks prior to delivery of the main stock of maize and added to it as the pit was filled (Plate III).

After the pit was filled it was covered with rubberized balloon-cloth sheets for two or three days as it was not possible to arrange for the final intended covering to be put into place immediately. The final covering is a single layer of ordinary "2-ply" bituminous roofing felt in strips 3 feet wide joined length-wise with 4 inches overlap. This is laid directly on the grain except for the central twelve feet where the grain was first covered with sheets of homogeneous insulating fibre board, half an inch thick. This provided a surface on which several people could walk and against which the felt could be pressed as the edges were sealed together.

Equipment

A scaffolding roof frame has been fixed over the pit so that it may be covered with a waterproof sheet if at any time the normal covering is damaged or has to be removed.

Temperature measurements are made by means of a six-point distant reading electric thermometer which incorporates life-tested thermistors as the sensitive elements. This system was chosen because of its relative cheapness and extreme ease of reading, in which respect it has a considerable advantage over thermocouples. Assurances have been given by the manufacturers of this equipment that the calibration of the thermistors will remain constant for a long period. In view of the poor reputation which earlier types of thermistor have had in this respect, however, it was decided to provide two thermistor elements at each point. After five months there is no sign of a deviation between any of the pairs.

Temperature measuring points are provided at top, middle, and bottom, on the centre line, and against three of the walls.

Four tubes (of polyethylene) are provided for withdrawing samples of intergranular air for gas analysis. These tubes terminate at the top, middle and bottom, centre line points and against one wall. Gas samples are withdrawn from these tubes by means of glass syringes and analysed on a standard Haldane gas analysis apparatus.

Changes in intergranular atmosphere

The following observations have been made in the first three months since the pit was filled at the end of July. The percentage of oxygen decreased rapidly, even before roofing was completed, falling below 0·4 per cent about 20 days after filling. It remained at or below this level for 30 days and thereafter slowly increased (presumably by slight leakage) and had reached just over 2 per cent 90 days after sealing.

The concentration of carbon dioxide rose in the first few days storage, the maximum value obtained, 4·4 per cent, being in the centre of the bulk. In other positions, notably on the north face in immediate contact with the concrete surface, the increase was even less, with maxima of 2·0 per cent to 3·5 per cent according to position. All maxima were reached at about the same time, i.e., ten days after the pit had been filled. Thereafter the carbon dioxide concentrations fell again to a minimum value between 0·3 per cent and 0·2 per cent after thirty days storage. Carbon dioxide then increased slowly, concurrently with the

increase in oxygen concentration, reaching 1·4 per cent 90 days after the pit was filled.

These very low concentrations of carbon dioxide were unexpected in view of the fact that so much oxygen had been absorbed. It is thought that they were caused partly by absorption of carbon dioxide by the fresh concrete lining of the pit, and partly by absorption of the gas by the grain itself. This pit differs from the experimental pits in Africa known to this Laboratory, in that all the African pits had their water vapour barrier layers on the inner surface of the concrete so that direct contact between grain and concrete did not occur. Nevertheless, carbon dioxide concentrations reported from African pits were exceedingly variable and generally much lower than had been expected. In several instances examination of the grain after storage in these African pits showed that most, if not all, insects had been killed although the observed levels of carbon dioxide concentration had not been sufficiently high to cause this result. It seems probable that oxygen concentrations had been lowered sufficiently to cause very high insect mortality while variable amounts of the carbon dioxide correspondingly produced had been lost, possibly by absorption. It has been suggested that some types of bituminous paint, such as were used as water vapour barriers in the experimental African pits, may pass a significant amount of carbon dioxide while preventing passage of water vapour.

It has recently been shown by S. W. Bailey working in Canberra, Australia, that, even if there is no differential absorption of carbon dioxide, insects are killed when infested grain is placed in hermetically sealed containers, not by excess of carbon dioxide concentration, but by deficiency of oxygen.

In the past it has been recommended that grain stored in underground pits should be kept under observation by regular determinations of carbon dioxide concentration in air samples withdrawn from the pits. The observations reported here show that oxygen measurements would be a much more satisfactory guide to the behaviour of the pit. Unfortunately it is less convenient to measure oxygen than carbon dioxide largely because the common oxygen absorbents, being alkaline, also absorb carbon dioxide. Attempts are therefore being made to find a satisfactory absorbent for oxygen which will not absorb carbon dioxide, and to develop a simple technique for its use in a gasometric apparatus. (*T. A. Oxley*, *Miss M. B. Hyde*, *K. Foulger*, *Miss G. Wickenden*, *Miss M. Keeping*).

HERMETIC STORAGE OF DAMP GRAIN

Observations on the 10-ton airtight silos have continued. The bin which had been filled in August, 1953 with uncleaned Atle wheat of 23 per cent moisture content had, in the spring of 1955, an intergranular concentration of carbon dioxide of about 76 per cent, the percentage having fallen slowly during the intervening period from the maximum of 95 per cent reached in September 1953. The oxygen concentration had remained at a very low figure, 0·1 to 0·2 per cent throughout.

The bin was opened for the first time at the end of February 1955, after eighteen months' storage. The grain at the bottom of the bin was at first compacted, but above this it was free-flowing, bright in colour and free from visible mould. As expected, the grain was non-viable. It had a strong sour-sweet smell and bitter taste, which were not removed by airing, and the flour milled from it produced an unacceptable loaf. About 2 tons of grain were run off from this

bin, dried, and used for poultry feeding tests (see below). The bin was finally emptied in July 1955, by which time occasional patches of mould had developed under the partially aerobic conditions created by the first and subsequent openings of the bin.

Another bin, which had been filled in September 1954, with Atle wheat of 18·9 per cent moisture content and charged with carbon dioxide from a cylinder, showed a progressive decrease in the carbon dioxide concentration from an initial value of 97 per cent to about 65 per cent by the end of November. It is possible that the fall in the first two months' storage was partly due to absorption of carbon dioxide by the damp grain, but a further decrease to 50 per cent by mid-January 1955 was more probably due to a small leak from one of the gas sampling tubes, for after this was traced and closed there was no further fall.

When this bin was opened in April 1955 the grain was, as expected, free-flowing, bright in colour and free from mould. It had a very slight sour-sweet smell and taste, indicating that there had been some deterioration in spite of the high initial concentration of carbon dioxide. The germination of the wheat was 82 per cent. The flour milled from this wheat, although it had a slight sour-sweet smell, produced a reasonable load with a barely detectable taint. On the second opening two months later the grain was similar in appearance, smell and taste, but the germination had fallen to 64 per cent.

The second bin used in 1954 was filled with wheat at a higher moisture than the first, namely 22·8 per cent., but no carbon dioxide was added. Owing to the cooler weather at and following harvest, and also probably to the better cleaning of the grain, which removed much green matter, the rate of carbon dioxide production was slower than in 1953 with wheat of similar moisture content, and the maximum concentration, 85 per cent, reached after nine weeks, was less than the maximum of 95 per cent attained in three weeks in 1953. The oxygen concentration fell to a very low level, 0·1 to 0·2 per cent, in four weeks.

In order to study the effect of withdrawing small quantities of grain from time to time, this bin was opened at intervals, varying between five and eight weeks, and about a ton of grain run off each time. After each opening the carbon dioxide concentration fell slightly, and did not rise again to its former level, so that after the fourth opening it was about 60 per cent. The small amount of oxygen introduced each time the bin was opened was absorbed within a few days, indicating that some aerobic activity was still possible. There was no further visual deterioration of the grain from the condition at the first opening, although after seven months' storage the germination was only 5 per cent. On each occasion the grain was free-flowing and mould-free, but had a noticeable "fruity" smell and taste. Although this was carried over to the flour, the bread, which was normal in appearance, had only a very slight taint.

A small stack of damp grain in sacks constructed as described in the previous report again showed no sign of heating until after several weeks' storage in an unheated shed.

The experiments of 1953 and 1954, both in the silo bins and in laboratory scale tests not described here, have shown that although wheat of up to 23 per cent moisture content can be kept under airtight conditions for as long as 84 weeks in a mould-free and free-flowing condition, such wheat is non-viable and has undergone chemical and other changes which have affected its milling and baking properties and produced a taint which renders it unpleasant for human consumption.

On the assumption that such grain would still be suitable for animal feed, it was decided to extend the tests in 1955 to grain such as barley, which is extensively used as an animal foodstuff. Two of the bins were accordingly filled in August 1955 with barley of medium moisture content (19·2 and 16·7 per cent) and one with wheat at 17·0 per cent. Measurements of gas concentration so far indicate that the rate of carbon dioxide production has been much slower than in previous years, although the oxygen fell to a very low level in only a few days. In small scale control samples, sealed in food cans, there is so far scarcely any detectable taint, even at the highest moisture content used. (*T. A. Oxley, Miss M. B. Hyde, Miss G. Wickenden*).

Respiratory quotient of damp grain

This year it has been possible for the first time to obtain a series of measurements of oxygen consumption and carbon dioxide production in sealed silos and hence to calculate the respiratory quotient. It has been found that the quotient for damp wheat and barley in the moisture range 16·7 per cent to 19·0 per cent is 0·75. The quotient is unchanged by decreasing oxygen concentration until this falls to about 5 per cent. The quotient then increases gradually as oxygen concentration further declines and rises sharply when about 0·5 per cent of oxygen remains. (*Miss M. B. Hyde*).

Poultry feeding tests with hermetically stored wheat

Several tests of the suitability of hermetically stored wheat for poultry feeding were conducted on a commercial scale in collaboration with Mr. R. P. Feltwell, County Poultry Adviser for Norfolk. In addition a laboratory scale test on young chicks was conducted by Dr. M. Coates at the National Institute for Research in Dairying.

Test 1. *On the farm of Mr. F. Siddall.* Two pens of laying hens, each containing about 250 birds on deep litter, were used. The birds had been laying well throughout the winter and the test covered the last six weeks of their laying life, from 4th March to 18th April. Each pen received wheat at the rate of 1–3/4 ozs per bird per day in addition to unlimited 20 per cent protein mash. The control pen received normal commercial wheat. The test pen received wheat which had been stored for 18 months in an airtight bin at a moisture content of 23·4 per cent and dried to about 15 per cent moisture content before feeding. This wheat, in view of its high moisture content and long period of storage, was regarded as an extreme example of hermetically stored grain, having a strong smell and somewhat bitter flavour.

The hermetically stored wheat was taken very readily by the birds. There was no sign of any adverse effect on their health and no effect on egg flavour could be detected. Birds in the test pens produced 2·6 per cent fewer eggs than those in the control pens but this difference was probably not significant.

Test 2. *At the National Institute for Research in Dairying*. Two samples of hermetically stored wheat were supplied, together with two corresponding control samples of the same wheat which had been dried at harvest time and stored under normal aerobic conditions. One sample of hermetically stored wheat had been stored for 18 months at a moisture content 23·4 per cent and subsequently dried; this was identical with that used in Test 1. The other sample was stored for seven months in a hermetically sealed bin (which, however, had been opened three times during the storage period) at a moisture content of

22·8 per cent and then dried. The latter was less severely affected than the former, by the usual flavour and odour of hermetic storage.

The tests were carried out on chicks from hatching to six weeks age. They were fed on a mash containing the unusually high proportion of 60 per cent wheat, experimental or control. Duplicate lots of 20 birds were allotted to each of the four diets. The birds were weighed five times during the six weeks and examined for abnormality.

The average weight of birds fed on mash containing hermetically stored wheat was slightly less than that of controls, and slightly less of the test diet was eaten. These differences, however, were statistically insignificant. No adverse effects were observed in any of the birds.

Test 3. A group of laying birds in a battery were fed with mash prepared by a commercial compounder, including a high proportion of hermetically stored wheat. It was reported that no differences whatever could be detected between these and control birds fed on normal mash.

Test 4. *At the Turkey Demonstration Centre, Norfolk Agricultural Station.* A group of 47 turkey chicks was fed from age 17 days to age 50 days on a mash containing hermetically stored wheat as the main cereal constituent. These gained 13·6 per cent less weight than a similar group receiving normal mash but showed no adverse qualitative effects. Owing to chance sex differences and the small number tested it is not possible to say whether the reduced weight gain is significant.

It may be concluded from these tests that hermetically stored wheat has no adverse effects on the vigour or health of poultry. The observation in tests 2 and 4 that slightly less hermetically stored wheat was eaten than control wheat, with corresponding reductions in body weight gain, though insignificant in each of the tests considered alone, may well be a real effect. Most of the wheat used for test exhibited the usual flavour and odour changes in an unusually marked degree owing to the high moisture content and long storage period; it is quite probable that it was less palatable than normal wheat. (*T. A. Oxley, Miss M. B. Hyde*).

MICROBIOLOGY

More intensive work on the microflora of hermetically stored grain was started towards the end of 1954 and has been continued during 1955. The basic method of investigation has been to seal a quantity of well mixed grain of known moisture content into a number of one pound metal food cans, to store these at constant temperature and to examine the contents of individual cans after different storage periods.

It has been shown that the viable mould count of grain put into hermetic storage falls rapidly, particularly at high moisture contents and temperatures: for instance, the count from wheat of 22 per cent moisture content in hermetic storage at 25°C may fall to less than 1 per cent of its original figure in eight weeks. Mycelial yeasts have only been found in large numbers where it could be shown that the storage vessels were not completely sealed. These results suggested that fungi are not an important cause of grain damage in hermetic storage so attention was turned to the bacteria. The results of preliminary observations on the bacteriology of hermetically stored grain although interesting have shown the need for a better examination technique. Work on this is now proceeding. (*G. Ayerst, D. Budd*).

INSECTICIDES

The main items in the programme of work have continued unchanged during the year but a number of small *ad hoc* investigations have been taken up chiefly to answer questions about insect infestation in tropical storage. In addition to these small investigations, more time has had to be devoted to advice on problems of insect control posed by Colonial Territories through the Colonial Liaison Officer. Some interruption of normal work has also been caused by Mr. Green's visit to the Gambia and the subsequent examination of the numerous samples from his experimental treatments. The time devoted to this has, however, yielded results of much interest.

Some 200 enquiries have been dealt with during the year by letter or telephone, mostly from existing knowledge, but occasionally involving an inspection or experimental treatment if giving promise of sufficient interest. To facilitate replies to enquiries about control of the Common Black ant, *Lasius niger*, a duplicated advisory note has been prepared summarizing present knowledge and experience.

In the past the Section has been largely occupied with measurements of the effectiveness of insecticides but it is felt that more attention should be given to evaluation of the performance of applicators for insecticides and a programme of work has now been initiated.

CONTROL OF INSECTS INFESTING GROUNDNUTS IN THE GAMBIA

Serious losses caused by insect infestation of harvested groundnuts led to a request from the Gambian Government that a member of the Laboratory's staff should study the problem in the Gambia and advise on methods of control. Up to 1954, the major part of the crop was exported in shell but machines have now been installed to decorticate all nuts before export. The nuts awaiting decortication and those kept for seed are stored in large heaps (seccos) of about 500 to 4000 tons and, at this stage, considerable damage is caused by the Groundnut beetle, *Caryedon fuscus*. The visit lasted about 3 months, during which a survey was made and large-scale experiments laid down, but with the co-operation of the Director of Agriculture and the Gambian Oilseeds Marketing Board, the experimental observations continued for some months longer. Results were assessed by the examination at the Laboratory of about 5 tons of samples; assistance in this was given by *G. T. Bills*, *Miss M. J. Kane*, *Miss D. G. Blackman*; *D. G. H. Halstead* and *Miss P. M. Davey*.

Survey

Extensive tours were made and inspections carried out at farms, native compounds, stores, trade depots, and decorticating and oil-extracting mills. (Plate IV.)

Infestation by *C. fuscus* begins in a minor way in the early part of the trade season and probably originates from small numbers of insects surviving the rainy season in food stores, old sacks, and overlooked nut debris. The beetles do not penetrate deeply into the mass of bulk-stored nuts and breed almost entirely in the surface layers. There is a rapid increase of population if nuts are stored for more than 6 to 8 weeks, particularly under cover. In one covered store the proportion of damaged surface nuts, which initially was so low as to be undetectable by the sampling method used, rose to 16·8 per cent in 3 months and 94·5 per cent in 4 months.

The Flour beetle, *Tribolium castaneum*, is endemic in the Gambia, where it lives on spillage in and around the decorticating mills and in almost all buildings in which groundnuts, rice or other stored foods have been kept. Serious infestations of groundnuts by *T. castaneum* have not yet occurred but become more probable as the amount of decortication increases.

Chemical control of the beetles

In experiments for control of *C. fuscus*, 55 heaps of undecorticated nuts, ranging approximately from 4 cwt to 15 tons and totalling about 200 tons, were treated with various doses and formulations of DDT and lindane. (Plate V). Dusts were a little more effective than wettable powders and, under Gambian conditions, had many practical advantages. Very good control was achieved both with 5 per cent DDT and 1 per cent lindane when dusted over the surface of the heaps. The lower dosage limits were about 2150 mg DDT per sq.m (roughly 1 lb dust per 100 sq. ft) applied as a single initial dose and 215 mg lindane per sq. m (roughly 1 lb dust per 200 sq. ft) applied at fortnightly intervals during storage.

In experiments for the control of *T. castaneum*, 30 small stacks, each containing 18 bags of decorticated nuts weighing a total of 27 cwt, were built near a decorticating mill known to be infested with *T. castaneum*. The exposed surfaces of the stacks were treated with various doses and formulations of DDT and lindane. In the following 4 months extremely heavy infestations of *T. castaneum* developed and little control was achieved by any treatment. Serious, although not quite as heavy, infestations of the Merchant Grain beetle, *Oryzaephilus mercator*, also developed in all bags. The infestations probably developed rapidly within the sacks from a small number of insects, or eggs, in the nuts at the time of bagging. Under such circumstances, treatment of the outside of a stack, or even of individual sacks, can exercise only limited control and the best way of preventing heavy infestations is to avoid a period of storage in tropical heat by shipping the crop immediately after decortication. In the Gambia, this is quite practicable.

Mechanical protection of groundnuts by sheeting

Encouraging results have been reported from laboratory trials of muslin as a mechanical barrier against cross-infestation of clean produce (*Pest Infestation Research*, 1954). In a small field trial, therefore, bagged, decorticated nuts were covered with closely woven cotton sheeting (a material originally made for parachutes), Each of three stacks, consisting of ten bags weighing a total of 15 cwt, was covered with a sheet the bottom edges of which were weighted with stones and buried under sand; three untreated stacks in adjoining insecticide trials acted as controls.

After 2 months, the sheeting began to show insect punctures. After 4 months, when the sheets were removed, they were riddled with small holes where they had been in contact with the sacks, were badly eaten by termites at ground level, and generally rotted by the bright sunlight. The groundnuts were very heavily infested with *T. castaneum* and *O. mercator*, the general impression being that the infestation developed within the stacks and that the sheets were punctured by movement of insects from the heap rather than to it. It was clear that this thin cotton sheeting was unsuited to use under the conditions described, but the protection that might nevertheless have been afforded to the groundnuts could

not be determined because the nuts were almost certainly infested when the sheets were put on.

Mechanical protection of groundnuts by lined sacks

Following the promise shown in laboratory tests (*Pest Infestation Research*, 1954) a practical trial was made of sacks with loose crepe-paper liners and with similar liners bonded to the jute with bitumen. Twenty of each and ten normal sacks were mechanically filled with decorticated nuts, stacked at the mill and left for 4 months. The entire 4 tons was then shipped to the Laboratory for examination.

The loose liners proved unsatisfactory at an early stage, most of them becoming badly torn when the sacks were filled. All were riddled with insect holes at the end of the storage period and the contents were heavily infested with *T. castaneum* and *O. mercator*.

The liners stuck with bitumen tended to tear when stitched after filling, but were otherwise in good condition when put into store. During storage, however, the combined effect of hot sunshine and oil from the nuts softened the bitumen and the lining tended to disintegrate. These lined sacks were far less pliable than normal ones and, in consequence, had fractured when dropped against protrusions during transit. Insects had passed freely through the lined sacking and had caused general perforation. All sacks contained very heavy infestations of *T. castaneum* and *O. mercator* and were rather more heavily infested than the normal unlined sacks. It again seemed likely that infested nuts had been put in the sacks. The reduced air circulation had caused some mouldiness and caking of the nuts. It was clear that the lined sacks used were unsatisfactory for holding groundnuts in the tropics. (*A. A. Green*).

CONTROL OF CACAO MOTH IN WAREHOUSES

When larval counts of the 1954 experiments (*Pest Infestation Research*, 1954) were concluded, it was found that virtually complete control had been achieved by all treatments except the DDT smoke. Some of these results confirmed those of the 1953 trials. The monthly spraying with pyrethrins plus piperonyl butoxide at only 2 pints per 2500 sq. ft of bag surface, and the use of unattended mist-generating machines were, however, being investigated for the first time and represented such a considerable saving in time and material as to warrant further trial. Additional trials were also planned for lindane smokes, because such treatments might well be suitable in buildings which were isolated or used for longterm storage: moreover, a different make of generator was found to give a less acrid smoke.

A new experimental site was chosen, the warehouse being much older than the one used in 1954, less well constructed and far more difficult to treat satisfactorily. There was considerable movement of commodities in and out of the stowages and, consequently, great variation among the areas treated. The tests were therefore more stringent than in previous years. The following treatments were given:

(1) A repeat of the 1954 treatment using a portable electric machine to apply, from a distance of 3–10 feet, a mixture of 0·3 per cent pyrethrins and 3 per cent piperonyl butoxide in heavy oil at the rate of 2 pints per 2500 sq. ft of bag surface per month, i.e. at one fourth the normal dosage rate.

(2) An equivalent dose applied as a space fog by two stationary unattended machines.
(3) A repeat of (1) using a paint spray gun and a petrol-driven compressor.
(4) A repeat of the 1954 treatment in which lindane smoke was applied at fortnightly intervals.
(5) As for (4) but the same dose applied monthly.
(6) Control stowage, not treated.

Weekly observations of numbers of moths were not possible for this experiment but some estimates were made during the peak-emergence period. Very few moths were found in the sprayed stowages (1 and 3), rather more where the smokes were used (4 and 5), and most where the unattended machines were used (2).

The degree of control was determined from the infestation of trap bags of larvae, as described in previous Reports. Counts of migrating larvae, although not yet concluded, indicate that good, but not complete, control has been achieved in all treated stowages. It seems likely that, under the difficult conditions prevailing, the dosages were at the lowest limit for reasonable efficacy. (*A. A. Green, G. T. Bills, Miss M. J. Kane, D. G. H. Halstead*).

SPRAYING AND DUSTING EQUIPMENT

It has been found increasingly important that practical advice on the use of insecticides for the control of insects infesting stored products should be accompanied by corresponding information on appropriate methods of application and types of machine. Arising from the needs of work and various enquiries, and in the absence of existing information, detailed assessments have been made of several machines. (*A. A. Green, G. T. Bills, P. S. Tyler*).

INSECT PENETRATION OF MULTI-PLY PAPER SACKS

In the Report for 1954 mention was made of the start of an *ad hoc* investigation to determine whether Flour beetles, *Tribolium castaneum*, could penetrate into three types of multi-ply paper sacks containing flour. At the end of the 17-week period of exposure to a high level of potential infestation, no holes had been bored through any of the plies, but a considerable infestation of larvae and beetles was present in the flour in two types of sack and very little in the third. This last was lined by a non-bonded polythene bag tied at the neck before stitching the outer plies. It is thought that beetles laid eggs under the sealing strip through which the top of each bag was stitched and that some of the first-stage larvae were able to find their way into the stitched ends of the sacks and thence into the flour.

Ancillary observations on the moisture penetration through the sacks showed that asphalt bonding of paper plies, bonding polythene to paper, or incorporating a non-bonded polythene liner prevented the uptake of moisture during 17 weeks in an atmosphere maintained at 85–95 per cent relative humidity. (*E. A. Parkin, C. J. Lloyd*).

INSECT INFESTATION OF COMPRESSED FLOUR

As an extension of the work reported above, the Laboratory was asked to determine whether flour, compressed into a wooden box, was still liable to infestation by stored product insects. A test showed that not only could the

flour serve for breeding of four species of insects commonly found in flour but it was also susceptible to infestation by the Rice weevil, *Calandra oryzae*, which cannot successfully breed in loose flour. (*E. A. Parkin, C. J. Lloyd*).

RESIN TREATMENT OF TARPAULINS

In some Colonial territories tarpaulins used for weather-proofing open railway wagons are said to be responsible for carrying insects from one consignment of goods to another. This is particularly difficult to obviate when the insects find harbourage in the hems. Treatment of hems during manufacture of the sheets with a urea-formaldehyde resin containing dieldrin was considered technically difficult, although preliminary laboratory tests indicated a good insecticidal effectiveness. A trial is now being made with some miniature tarpaulins to ascertain the value of resin treatment of seams and grommets after manufacture. (*E. A. Parkin, Mrs. E. I. C. Scott, D. W. Hall*).

BHC SMOKES AND EMPTY SACKS

The disinfestation of empty sacks before re-use is a constantly recurring problem, especially when facilities for fumigation are not available. Preliminary tests to discover whether BHC-smoke generators would be useful for this purpose did not give very promising results and further trials were not made. It was felt that the same moderate level of effectiveness could be more economically attained by other methods of applying BHC. (*Mrs. P. J. Maycock, Miss D. G. Blackman*).

INSECTICIDAL EFFICIENCY OF BORNU DIATOMITE

Work carried out some years ago by the Laboratory had shown that a certain type of colloidal silica dust was very insecticidal to several stored product pests. Moreover, this dust could be applied in water suspension by a spraying machine, and, when dry, the residue was sufficiently friable to be easily broken up and accumulated by the insects.

During discussions with the Officer-in-charge, West African Stored Products Research Unit, it was pointed out that such a dust might be very useful for insect control on bagged commodities in Northern Nigeria where temperatures are high and relative humidities low for a considerable part of the year and local high winds make the application of dry dusts difficult and wasteful. Preliminary laboratory trials in Nigeria gave promising results but the cost of the silica preparation was high and the Pest Infestation Laboratory was therefore asked to assess the possibility of using a diatomite available at Bornu, Northern Nigeria, at low cost.

A sample of the diatomite was sieved, milled, and elutriated by the Mineral Resources Division, Colonial Geological Surveys, into various fractions for insecticidal evaluation. The fraction of smallest particle size gave encouraging results as a dry dust against the Granary weevils, *Calandra granaria* and *C. oryzae*, and the Flour beetle, *Tribolium castaneum*. However, when tested after application as a suspension in water, the diatomite was ineffective, because the dry residue caked too hard to be re-powdered and picked up by the beetles as they walked over it.

Tests of caking of various dusts on drying from water suspension showed that diatomite and gypsum tended to form a hard crust whereas talc, kaolin, and

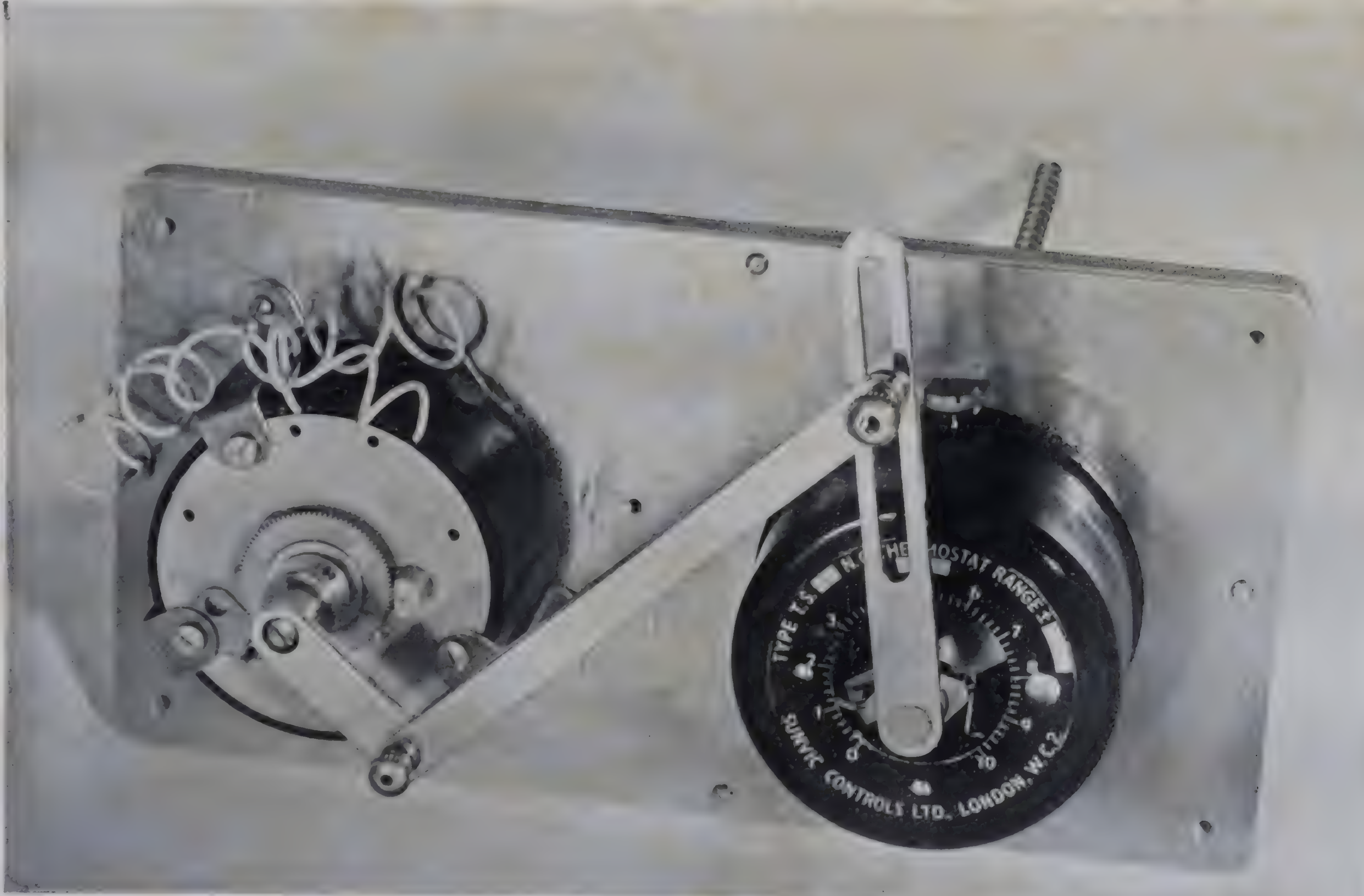

PLATE I. *Variable temperature thermostat* (*see p.* 9)

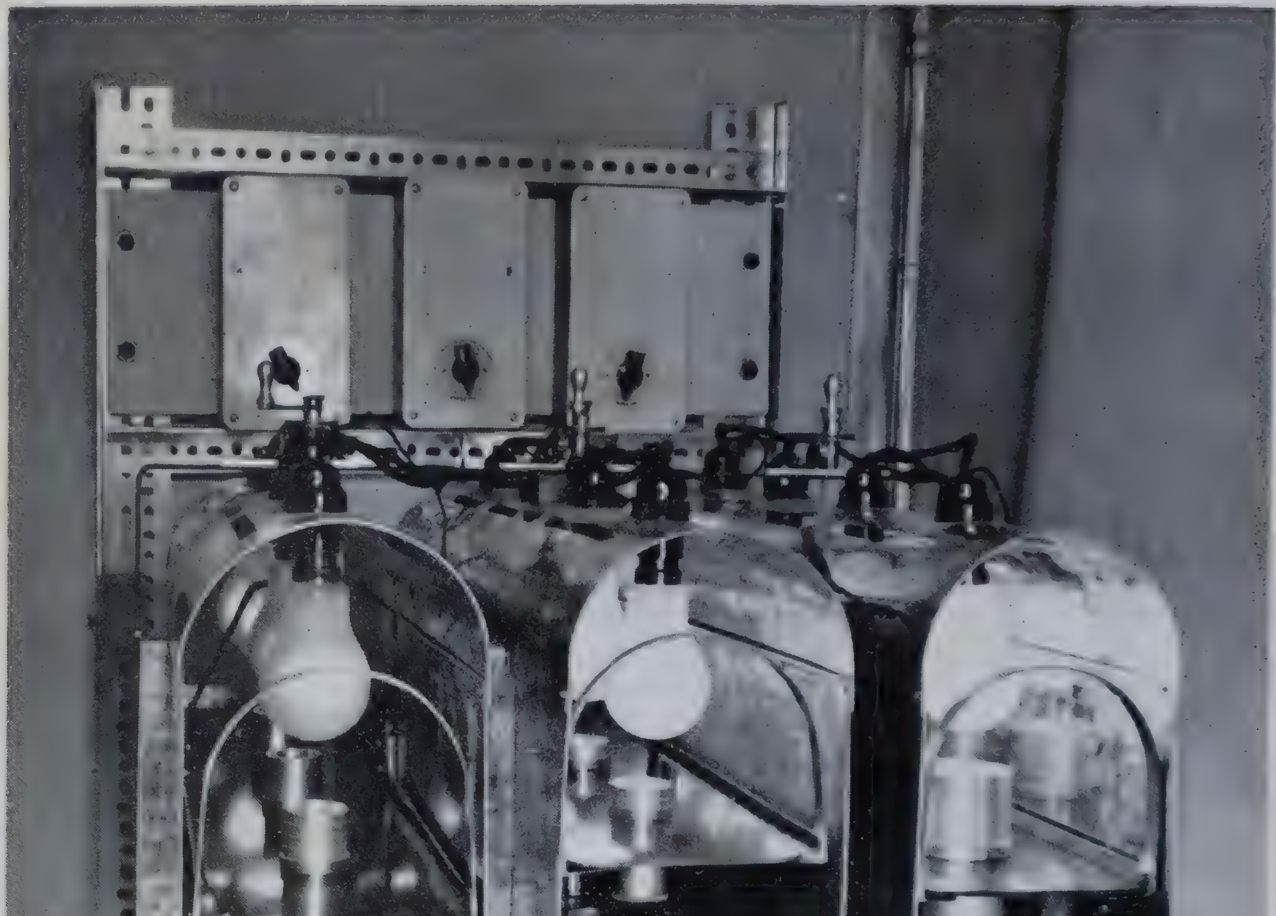

PLATE II. *Apparatus for extracting insects and mites from samples of grain* (*see p.* 14)

PLATE III. *Filling experimental grain storage pit* (*see p.* 19)

PLATE IV. *Examining Gambian groundnuts in the field for infestation by the Groundnut beetle* (*see p.* 24)

PLATE V. *Experimental control of Groundnut beetles in the Gambia* (see p. 25)

PLATE VI. *Apparatus for applying insecticide to single insects while under anaesthesia* (*see p.* 30)

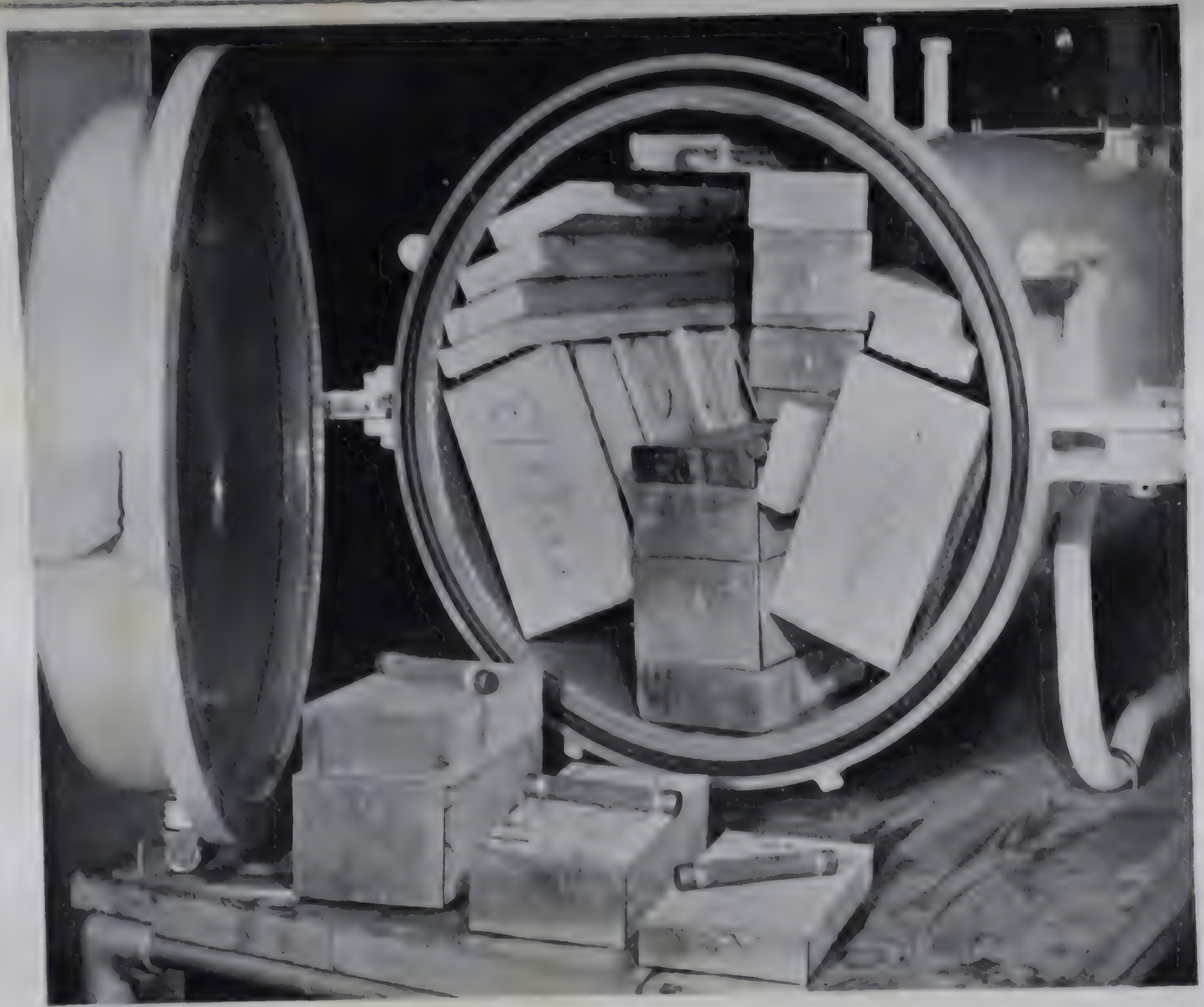

PLATE VII. *Experimental fumigation of timber with methyl bromide* (see p. 36)

PLATE VIII. *Fumigation of H.M.S.* Victory (*see p.* 37)

some colloidal silica and alumina preparations remained fairly friable. (*E. A. Parkin, Mrs. E. I. C. Scott*).

RELATIVE SUSCEPTIBILITY OF INSECTS TO INSECTICIDES

As reported last year, a series of experiments has been done so that a wide range of stored product insects can be grouped according to their susceptibility to pyrethrin and pyrethrins+piperonyl butoxide. The results are now being analysed and a report is being written. For nearly every species tested, the larva has proved more resistant than the adult. Among the adults of the different species, those that are very active and have a short natural adult life were nearly all very susceptible. (*C. J. Lloyd*).

In extension of some work reported in 1952, the effectiveness of a gamma-BHC dust has been determined for controlling the Lesser Grain borer, *Rhyzopertha dominica*. The beetles were quickly killed and reproduction prevented by 0·625 parts per million of gamma-BHC in wheat. (*E. A. Parkin, Mrs. E. I. C. Scott*).

Gamma-BHC slowly vaporizes and its vapour is very toxic to many species of stored product insects. Tests have been started to investigate the relative toxicity of the vapour to a series of the common species of beetles and their larvae. The results so far obtained do not entirely fit in, however, with expectations from the work with dusts. Of particular interest, is the approximate equality in speed of kill of the Granary weevils, *Calandra granaria* and *C. oryzae*, and of adults of the Saw-toothed Grain beetle, *Oryzaephilus surinamensis*; this last species proved much more resistant than the Granary weevils when exposed to BHC dust in grain (*Pest Infestation Research*, 1952). Some explanation is being sought experimentally for this. (*E. A. Parkin, Mrs. E. I. C. Scott*).

PYRETHRUM-RESISTANT GRAIN WEEVILS

A pyrethrum-resistant strain of the Grain weevil, *Calandra granaria*, has been obtained from a commercial source. Compared with the Laboratory's stock the beetles were smaller, about 8 per cent less in weight, and darker in colour. The two strains readily interbred.

When exposed on films of pyrethrum in oil, the beetles proved to be about four times as resistant as the Laboratory's stock; but when compared by a direct-spray method the resistance was twice that of the P.I.L. strain.

Tests will be made at intervals to ascertain whether the strain retains its resistance during culture for several generations and to find out whether the resistance can be markedly raised by breeding from the survivors of a pyrethrum application in each generation. (*C. J. Lloyd*).

TOXICITY OF MALATHION TO INSECTS

Malathion, an organo-phosphorous insecticide of relatively low mammalian toxicity, is being investigated, and appears likely to be useful in the control of stored product insects. In laboratory tests it has been found highly toxic to adults of the Flour beetle, *Tribolium castaneum*, of the Grain weevil, *Calandra granaria*, and of the Cacao moth, *Ephestia elutella*. It was rather less toxic to larvae of the Cacao moth, and of the Khapra beetle, *Trogoderma granarium*. Like gamma-BHC, malathion has a vapour toxicity, but films on wood remained toxic longer than similar films of gamma-BHC. (*K. G. Gostick*).

Confinement of Cacao moth caterpillars on bricks treated with wettable powders showed that a deposit of 20 mg malathion per sq. ft caused paralysis

and death more rapidly than deposits of 20 mg gamma-BHC or 80 mg DDT per sq. ft. With both the latter insecticides a few caterpillars managed to pupate and moths emerged, although the majority of these showed symptoms of toxic effects. (*Mrs. E. I. C. Scott*).

RETENTION OF SPRAY BY INSECTS

When crawling insects are treated with a liquid insecticide by means of a laboratory spray tower, the dose they receive is normally measured indirectly. It is assumed that they will acquire the same dose (expressed as mg per sq. cm) as is determined by spraying a substrate under the same conditions but without insects on it. However, after being sprayed, the insects lose a substantial proportion of the original dose to the walls and floor of the clean container to which they are transferred for observation.

The actual weights of spray retained by beetles of three species have been investigated for relative doses of from 0·3 to 1·0 mg per sq. cm. Groups of beetles were sprayed with a dyed oil and washed with a solvent; the amounts of dye recovered were estimated photo-electrically. The amount of oil retained by the beetles could thus be determined.

During application of the spray, Flour beetles (*Tribolium castaneum*) acquired a deposit of oil in accordance with expectation, based on the relative dose and their projection area. Grain weevils (*Calandra granaria*) and Australian Spider beetles (*Ptinus tectus*), on the other hand, showed deposits 20–30 per cent higher than expected. Three hours after transfer to clean containers, the Flour beetles retained only 20 per cent of the original dose, whereas the Grain weevils and Spider beetles retained 50 per cent and 70 per cent respectively. The differences between the retentions are understandable in the light of differences in form, structure and locomotor activity between the species.

More detailed work on the Flour beetles showed that the weight of oil retained fell to a steady level in about one hour after spraying. Inclusion of allethrin in the oil to modify the behaviour of the beetles did not materially affect the results. (*K. G. Gostick*).

METHODS FOR TOPICAL APPLICATION OF INSECTICIDES

The method for topical application of insecticides to insects by means of micro-capillary tubes has been increasingly used. The tubes are easily calibrated by delivery of odourless petroleum distillates from them into suitably calibrated lengths of precision-bore capillary, and measurement of the lengths of the liquid columns. The precision-bore tubing has thick walls, and so cannot itself be used for the topical application.

An apparatus has been constructed for keeping insects under anaesthesia during dosage by means of micro-capillary tubes (Plate VI). The insects are put into a circular channel on a turntable, and gaseous anaesthetic is passed through the channel. This is roofed by a non-rotating "Perspex" disk, and rotation of the table brings the insects successively beneath a hole in the disk, through which the micro-capillary, mounted in a holder, is inserted. (*P. S. Hewlett, M. A. Cordaroy*).

INJECTION OF COCKROACHES

A technique has been developed for injection of German cockroaches, *Blatella germanica*, with insecticides. Each cockroach was injected with 0·5 µl or

more of liquid by means of a micrometer syringe fitted with a device for semi-automatic repeated deliveries of each selected volume. Satisfactory formulation of the insecticides for injection proved difficult, because most of the liquids in which contact insecticides are highly soluble (e.g. acetone) were too toxic by themselves. The heavy oil, Shell Risella oil 17, was a suitable solvent in that it was non-toxic at convenient doses, and the percentage mortality of the insects rose with increasing concentration of insecticide in the oil. However, the oil solution did not disperse through the body, dissection of cockroaches showing that the injected oil remained as a globule near the site of injection and a membrane (presumably of agglutinated leucocytes) formed round the globule. When acetone containing an oil-soluble dye was injected, most of the dye appeared to be taken up by the tissues near the site of injection. (*K. G. Gostick*).

FUNDAMENTAL STUDIES WITH SOLUTIONS OF INSECTICIDES IN HEAVY OIL

The fundamental studies on the action of solutions of insecticides in heavy oil applied topically to Black Fungus beetles, *Alphitobius laevigatus*, are nearly complete. The object of the last part of the investigation has been to determine how the toxic effects of doses of one insecticidal solution applied simultaneously to different parts of the insect are summed. It has been found that this situation can be regarded as a special case of the similar joint action of different insecticides. The mathematical equations for similar joint action developed at the Laboratory by Hewlett and Plackett in 1952 were required to account for the experimental results; the equations put forward previously by other workers failed to do so. (*P. S. Hewlett, Miss C. Belcher*).

RESPIRATION OF INSECTS TREATED WITH INSECTICIDE

The oxygen uptake of Black Fungus beetles, *Alphitobius laevigatus*, dosed with various contact insecticides has been determined. The beetles were treated topically with solutions of the insecticides in heavy oil, and afterwards put into respirometers at 25°C. High and low doses were used, the former sufficient to kill all the beetles, and the latter insufficient to kill any.

Interesting results were obtained with allethrin. Both high and low doses quickly knocked down all the beetles, before they could be put into the respirometers. In developing symptoms of poisoning the beetles did not become unusually active, or scarcely so. The oxygen uptake of those treated with low doses remained at, or a little below, normal. The uptake of those treated with high doses rose for about one hour, when it had reached about 10 times the normal, then fell. Since the beetles remained knocked down meanwhile, the increased uptake was probably not due to increased muscular activity. (*P. S. Hewlett, J. A. McFarlane*).

STATISTICAL ASPECTS OF INSECTICIDAL ACTION

In collaboration with Mr. R. L. Plackett, of the Department of Applied Mathematics, University of Liverpool, a short theoretical study has been completed of the relationships between the quantal and graded responses of biological material following the administration of a drug. A paper is in press. (*P. S. Hewlett*).

CHEMICAL ASSAY OF PYRETHRUM

Since the introduction of the 2:4-dinitrophenylhydrazine method for collective assay of the pyrethrins, the chemical reactions involved have been studied in more detail. Several compounds which serve as the basis for the photometric determination have now been isolated and spectrophotometric measurements have confirmed the anticipated close relationship of their absorption spectra. This has established the validity of the use of α—(±)—trans-allethrin as a standard substance.

Tests with model compounds have afforded additional information on the fate of some of the non-insecticidal constituents of pyrethrum oleoresin during the course of the analysis. Only one case of interference has been found so far: the inactive pyrethroids (esters of pyrethrolone and cinerolone with higher fatty acids) assay as about 80 per cent of their weight of pyrethrins. This source of error cannot be avoided at present but is unlikely to be serious in practice, since the compounds in question appear to be no more than minor contaminants of commercial pyrethrum preparations.

An account of this work is being prepared for publication. (*B. P. Moore*).

SYNTHESIS OF CONTACT INSECTICIDES

The investigation of the insecticidal properties of the β-triketones has continued and approximately thirty compounds of this type have now been examined. Relatively few of these have failed to show activity when applied topically to Black Fungus beetles, *Alphitobius laevigatus*, but so far none has exceeded valone (2-*iso*-valeryl-1:3-indandione) in potency. Some general trends are already apparent but further syntheses are contemplated before the attempt is made in detail to correlate activities with chemical constitution. (*B. P. Moore*).

VARIATION IN INSECT RESISTANCE

Regular monthly testing on beetles from the standard stock of the Confused Flour beetle, *Tribolium confusum*, has continued, using the same experimental technique as in previous tests. The mortality data show a more consistent and closer agreement with linear relationship of probit mortality on log exposure period than in previous years. None of the eleven replicated tests was heterogeneous and the total heterogeneity χ^2 value for the series has a probability between 0·7 and 0·9. The mean level of resistance has been slightly lower and the mean range slightly greater than the corresponding values of last year. The variability of level of resistance has been about the same as last year, while that of range of resistance has been greater, both being somewhat in excess of random variation. Additional tests at 25°C have been made on beetles from the standard stock to investigate the relationship between mortality and the two dosage factors, concentration and exposure period. Separate mortality data for males and females have been obtained at concentrations between 10 and 125 mg per litre and exposure periods of about 10–4000 min (i.e. 10 min to 3 days). Above about 17 mg per litre for males and 20 mg per litre for females probit mortality and log exposure period were linearly related, the slope of the regression line being about 10 up to a concentration of 40 mg per litre, and decreasing to about 5 at the highest concentrations used. Probit mortality and log concentration did not show a linear relationship except over restricted ranges of concentration. Below about 17 mg per litre for males and 20 mg per litre for females probit mortality was not linearly related to either dosage factor. In this

region of concentrations, maximum mortality in any single test was achieved after about 1000 min exposure and no higher kill was caused by prolonging the exposure period to 4000 min: the maximum mortality was dependent on the concentration. With exposure periods in excess of 1000 min, beetles were readily classified on removal from the fumigant as either "knocked-down" or "active". Those in the first group remained knocked-down and subsequently died, whereas those in the second survived. There were indications of an absolute tolerance threshold of concentration of about 5 or 6 mg per litre. There may be linearity of probit mortality on log (concentration threshold) at effective concentrations up to about 40 mg per litre.

The two resistant strains of Flour beetles have been maintained with each generation bred from survivors of fumigation. As anticipated, there has been no marked change from the level of resistance reported last year. A few tests have been made on the resistant strains over a wide range of concentrations and exposure periods for comparison with the similar tests on the standard stock. (*J. A. Hope, Miss R. Phillips*).

MOTHPROOFING TESTS

Participation has continued in the tests arranged by the Mothproofing Committee of the International Wool Textiles Organization. The repetition of a standard series of test exposures at intervals over a period of 18 months has now been concluded. The variations in weight loss encountered in this Laboratory's series do not appear to be seasonal and their cause is not known. Their importance can, however, be reduced by working always with a set of reference patterns exposed at the same time as those under investigation.

In collaboration with other laboratories, some attention has been given to determining whether conversion factors can be obtained for a variety of woollen materials which will enable weight losses from them, resulting from exposure to moth larvae under controlled conditions, to be converted into expected weight losses from the standard serge. Preliminary results at the Pest Infestation Laboratory are not too promising. (*E. A. Parkin, Mrs. P. J. Maycock, Miss D. G. Blackman*).

CONTROL OF PHARAOH'S ANT IN HOSPITALS

Extensive baiting of the tuberculosis sanatorium which was treated with chlordane in December, 1953 (*Pest Infestation Research*, 1954), showed it to be still free of infestation by Pharaoh's ant, *Monomorium pharaonis*, 20 months after the initial treatment.

In view of the success of this treatment, the hospital authorities were anxious that a second, similarly infested sanatorium should be treated. It was suggested that they should employ their own team of operators and that the Laboratory would arrange suitable instruction and training. Two workmen were instructed in all aspects of the treatment.

The hospital was larger than the one previously treated and consisted of eight wards, each 100 yards long, and eleven other buildings including some with two or three stories. All buildings were isolated geographically but had intercommunicating ducts carrying the hot water pipes and other services. Most of this ducting was accessible only by lifting concrete slabs. Chlordane treatment was applied as in the first sanatorium, except in the accessible ducting where a large fogging machine was used with a dosage rate of 3 pints of insecticide to each

40 ft of 4 by 6 ft ducting. Unfortunately, the operators were only employed part-time on ant control and the initial treatment was spread over a period of about 12 weeks. Post-treatment baiting has located very many nests and there is a general indication that ants surviving the initial treatment have been given time to multiply to such a degree as to be difficult to eliminate by the usual subsequent local treatments.

It is clear that large scale treatments of this sort are likely to be successful only if carried out speedily, extensively, and thoroughly. (*A. A. Green*, *Miss M. J. Kane*).

CONTROL OF COCKROACHES

Laboratory tests

Tests of urea-formaldehyde resins containing various insecticides have been made against adult females and last instar nymphs of the German cockroach, *Blatella germanica*, and the Oriental cockroach, *Blatta orientalis*. The insects were exposed continuously on hardboard coated with insecticidal resin and comparisons were made between times required for 50 per cent knock-down. The formulations tested included DDT at concentrations of 5, 10 and 20 per cent, gamma-BHC at 1, 5, and 10 per cent, dieldrin at 5 and 10 per cent, and the following mixtures: 10 per cent DDT+5 per cent gamma-BHC, 20 per cent DDT+2 per cent gamma-BHC, and 10 per cent dieldrin+5 per cent aldrin.

Three days after application, when the first exposures were made, the most effective film was the mixture of 10 per cent DDT+5 per cent gamma-BHC. All formulations lost toxicity during 6 months storage, and 10 per cent dieldrin became the most effective film. Comparative tests using odourless kerosene as the solvent for 5 per cent DDT, 1 per cent gamma-BHC, and 5 per cent dieldrin, indicated that only with dieldrin had the persistent toxicity been increased by incorporation in resin. (*G. T. Bills*).

Field tests

A visit was made to a banana ripening depot following an enquiry about control of cockroaches in hands of bananas at retail stores. Baiting tests and inspection indicated that there was no endemic infestation of the ripening rooms. After laboratory tests had shown that there was little risk of taint, one ripening room full of bananas was treated with DDT smoke and left closed overnight. Sixteen cockroaches of five species all indigenous to the West Indies were found beneath the hanging fruit. It was concluded that complaints about cockroaches at the retail stage of handling were probably caused by small numbers of insects hidden among the closely packed bananas and transported from the country of origin. (*G. T. Bills*, *Miss M. J. Kane*).

FUMIGANTS

At the request of the Grain Marketing Board of Southern Rhodesia two members of the Section, Mr. W. Burns Brown and Mr. H. K. Heseltine, have visited that country to carry out tests of the circulatory fumigation plant in the Board's new silo at Aspindale, Salisbury, and to advise on its operation. A description of the plant and of the tests follows below. This was the first overseas visit by members of the Section made with the purpose of carrying out experimental work and the

selection of testing equipment suitable for air transport posed some new problems. The experience gained will prove valuable in any similar expeditions which may be called for in the future.

At the request of the Maize Control Board of Northern Rhodesia Mr. Burns Brown also visited that territory to advise on the provision of circulatory fumigation plants in the Board's existing and projected silos.

The special facilities of the Section for carrying out tests with fumigants have been drawn upon to assist in the investigation of a number of problems involving timber-boring insects which are the special province of the Forest Products Research Laboratory at Princes Risborough. In addition to collaboration between the two laboratories on the fumigation of H.M.S. *Victory* against the Death Watch beetle and on the fumigation of packing case timbers against *Sirex* wood wasp a few tests have been made of the toxicity of methyl bromide to other timber boring insects.

As in previous years, a feature of several of the large scale investigations has been the close collaboration between the Laboratory and the Headquarters Chemical Branch of the Infestation Control Division, Ministry of Agriculture, Fisheries and Food.

TESTS OF CIRCULATORY FUMIGATION PLANTS IN SILOS

For some years the Laboratory has been advocating the provision of gas circulating systems in grain silos to permit efficient treatment with methyl bromide. Two opportunities have occurred during the year for testing the effectiveness of such installations.

Aspindale Silo of the Grain Marketing Board of Southern Rhodesia

This recently completed silo consists of 36 main circular bins each 24 ft in diameter, 100 ft deep, and of approximately 900 tons capacity with 24 interspace bins each of 500 to 600 tons capacity. All these bins have been fitted for gas circulation using a combination of piping and flexible pipe connexions. The fan unit (approximately 1200 c.f.m.) and equipment for application of the fumigant is mounted upon a movable trolley on the top floor of the silo. Tests of pressure, airflow, and of fumigant concentration made on one of the main bins filled with white horse tooth maize and on an interspace bin filled with native beans showed that satisfactory gas distribution was obtained at the bin bottom and that circulation for one hour after application of the fumigant was sufficient. On the basis of the tests recommendations were made for the efficient and safe operation of the plant. (*W. Burns Brown, H. K. Heseltine*).

Silo of a Food Factory near London

A single small bin in this silo has been fitted for gas circulation. It measures 6 ft square and about 100 ft deep and has a capacity of about 75 tons. The top and bottom of the bin are connected by fixed piping with the small fixed fan unit. With the bin filled with yellow maize the air flow was estimated to be 62 c.f.m. giving one complete change of the intergranular air in about 23 minutes. In spite of this rather low rate of air change concentration measurements showed that a satisfactory distribution of fumigant was obtained by circulating for about one hour. (*W. Burns Brown, H. K. Heseltine, J. D. Pearson*).

FUMIGATION OF TIMBER AGAINST *SIREX* WOOD WASP

Recent Australian quarantine regulations require that all softwoods showing evidence of damage by *Sirex* wood wasps shall be treated to prevent the introduction of the insects into Australia. Failing such treatment in the country of origin, it may be carried out in Australia at the expense of the exporter. This situation affects British exporters of goods packed in softwood cases and crates. From a consideration of the various available methods of treating timber or packing cases it appeared that fumigation with methyl bromide of piles of timber under gas-proof sheets might prove the most practical and economical solution to the problem. The method had been applied in Australia where detailed recommendations for carrying out the treatments had been issued, though no data had been published showing the toxicity of methyl bromide to *Sirex* or the effectiveness of the practical treatments against this insect. The Fumigant Section of the Pest Infestation Laboratory has collaborated with the Forest Products Research Laboratory in a series of tests designed to provide data upon which recommendations for treatments in the United Kingdom could be based.

A brief description of the problem and of the investigations which have been carried out in this country has been given by Dr. R. C. Fisher (*Forest Products Research Laboratory*).

Field trials

Trial fumigations were carried out on piles of between 6 and 9 standards of $\frac{7}{8}$ in by 4 in redwood and whitewood timbers, stacked under different conditions, the distribution of fumigant being investigated by the measurement of gas concentrations. Each stack was covered by a single gas-proof sheet and the dose of methyl bromide was calculated according to the Australian recommendations. The tests demonstrated the need for reasonably good conditions of stowage if a satisfactory distribution of fumigant was to be obtained. (*W. Burns Brown, H. K. Heseltine, J. D. Pearson*).

Toxicity of methyl bromide to Sirex *larvae*

Sirex larvae were obtained at the Forest Products Research Laboratory by cutting up freshly felled trees. Small samples were exposed to a range of concentrations of methyl bromide for 24 hours in a fumigation chamber at 15°C and 70 per cent relative humidity. The insects showed an unexpectedly high resistance to the fumigant. It is not possible to estimate from these results the dose required for a high percentage kill of freely exposed larvae but it is several times that necessary for the most resistant of the wide range of stored product insects hitherto tested. (*Miss E. M. Reynolds, S. G. Heuser, Miss M. F. East*).

Penetration of methyl bromide into softwood timbers

An attempt was made to determine the dosage factor which must be used to allow for slowness of penetration of methyl bromide into timber by fumigating pieces of softwood containing insect samples in a central cavity (Plate VII). The heartwood and sapwood of Norway Spruce and Scots Pine were tested. The insects used were the adults of *Calandra granaria* and the older pre-adult stages of the same species inside wheat. Data on the resistance of these insects to methyl bromide are available. The transverse ends of the timber pieces were sealed with paraffin wax and lead foil. It has proved difficult to derive from

the results any precise estimate of the dosage factors required but it seems likely that for some types of 1 in board a factor of 2 may be necessary and that thicker boards may require higher factors. (*Miss B. D. Hole, J. D. Pearson*).

Conclusion

The exceptionally high resistance of *Sirex* larvae to methyl bromide shown in the laboratory tests leads to the conclusion that the fumigation of packing case timbers for complete control of this species would require such high doses of the fumigant as to be unpractical. In the absence of adequate supplies of suitably infested timbers which would be needed to test this conclusion under practical conditions no further tests have been planned.

SECOND FUMIGATION OF H.M.S. *VICTORY*

A second fumigation with methyl bromide of H.M.S. *Victory* against the Death Watch beetle was carried out in the week beginning May 16th (Plate VIII.) The later date was chosen (*a*) to allow some further assessment of the effectiveness of the 1954 fumigation as judged by the emergence of beetles during April and the early part of May and (*b*) in the hope that fumigation at this time would be effective in reaching an increased number of adults as well as destroying recently laid eggs and young larvae on or near the timber surfaces. The number of beetles systematically collected during the period before fumigation were again on the reduced scale of the 1954 collection.

The fumigation was carried out as in 1954 except that an additional dose of fumigant equal to half the initial dose was applied after 24 hours. The fumigation was continued for a total period of 48 hours. Gas concentrations were measured as in 1954 but in spite of the increased dose the concentration-time (c.t.) products were little or no higher. This was probably the result of a higher rate of leakage since strong winds were blowing for most of the fumigation period.

Again an attempt was made to assess the penetration of methyl bromide into oak timbers by exposing groups of oak blocks 4 in by 4 in by 6 in at various gas-sampling positions. Test insects (the older pre-adult stages of *Calandra granaria* in wheat) where confined in cavities in the blocks the transverse ends of which were sealed with paraffin wax and lead foil. The results indicate that penetration even for a distance of only 1 in into sound oak timber is very seriously restricted. (*W. Burns Brown, H. K. Heseltine, S. G. Heuser, Miss B. D. Hole, J. D. Pearson.*)

In collaboration with the Forest Products Research Laboratory some determinations of the toxicity of methyl bromide to the freely exposed adults and eggs of the Death Watch beetle, *Xestobium rufovillosum*, have been made. The tests were made at 15°C and 70 per cent relative humidity. The results of the tests with adults suggest that a concentration time product of 200 mg. h per litre would be required for 99·9 per cent kill two days after fumigation and a product of 100 would give an equally high kill three or four days after fumigation. This latter c.t. product should give control of the eggs. (*Miss. E. M. Reynolds, S. G. Heuser, Miss M. F. East*).

FUMIGATION OF STACKS OF BAGGED FLOUR UNDER GAS-PROOF SHEETS

Following the small scale tests with methyl bromide described in last year's report (p. 28) three full scale fumigations have been carried out in collaboration with the Infestation Control Division, Ministry of Agriculture, Fisheries and Food.

The first of these tests was on a 3000 cu. ft stack fumigated with methyl

bromide at a dose of 3 lb/1000 cu. ft for 24 h. The object of the test was to investigate the distribution of fumigant throughout the stack and to carry out baking tests. The results showed a very bad distribution of fumigant. High concentration time products (up to 360 mg h per litre) were obtained in the channel at the top of the stack, and also at the bottom of the stack, whilst low products (down to 50) were obtained in bags half way up the stack, especially in those near the centre of the stack. Baking tests showed no damage to the flour. The second test was on a similar stack and at the same dosage rate. An attempt was made to obtain a more even distribution of fumigant in the stack by the use of a 12 in. electric desk fan placed at one end of the channel behind the jet and blowing down the channel. The use of this fan had to be abandoned after a few minutes as it caused a great increase in the amount of fumigant escaping at the junction of the sheets and the concrete floor. Although the free space concentrations were more even in this stack, there was little improvement in the distribution of fumigant in the bags.

A third test was carried out by the method using ethylene oxide and crushed solid carbon dioxide as a comparison with the methyl bromide method. The distribution pattern for ethylene oxide was similar to that obtained with methyl bromide although a good distribution of carbon dioxide was achieved. Some concentrations were still rising after 48 hours so it is possible that better results could be obtained with either fumigant by the use of longer fumigation periods.

Further tests are contemplated to investigate such factors as the period of fumigation, techniques for stirring the air under the sheet, and methods of sealing the sheets to the ground. (*H. K. Heseltine*, *J. D. Pearson*).

FUMIGATION OF BULK GRAIN WITH PHOSPHINE

Tests have been made of a German fumigation process which consists of the addition of tablets to grain stored either on floors or in silo bins. The active material in the tablets is aluminium phosphide which decomposes on exposure to moist air, with the evolution of phosphine. The material has now been made available for experimental treatments in this country by a servicing company and the Laboratory has collaborated with the Infestation Control Division, Ministry of Agriculture, Fisheries and Food in two tests. The first test was on a hundred tons of grain held behind wooden bulkheads on a warehouse floor and the second on grain stored in silo bins of a hundred tons capacity. In both cases, test insects were used and some gas sampling was carried out. The assessment of the results is not yet complete and further tests are contemplated. (*H. K. Heseltine*, *S. G. Heuser*, *Miss B. D. Hole*, *J. D. Pearson*, *J. B. Waller*).

INSTRUMENTS FOR THE ESTIMATION OF HALOGENATED HYDROCARBONS IN AIR

1. The gas thermal conductivity meter used for the estimation of methyl bromide has been fitted with a new type of cell by the makers. This has increased the speed of response considerably and a reading can now be obtained in less than two minutes with a sample of about 50 ml. This instrument was used for the tests in Southern Rhodesia described earlier in this Report. Further modification is desirable before the instrument is suitable for use by unskilled personnel, and in view of the interest shown in the instrument by fumigation operators, especially in Africa, work is being continued on the instrument in close collaboration with the manufacturers. (*H. K. Heseltine*, *J. D. Pearson*, *J. B. Waller*).

2. A newly available commercial instrument, the sonic gas analyser, has been acquired for the estimation of fumigant concentrations in air. This is a non-specific instrument which can estimate concentrations of any gas in air provided that the velocity of sound in the gas differs appreciably from that in air. The instrument has been checked under various conditions with concentrations of methyl bromide in air and has shown good reproducibility over the period of test. It has a rapid response and requires a sample of the order of 200–300 ml. Certain sampling difficulties have yet to be overcome, when it is hoped that the instrument will prove of considerable use in fumigation trials in the field. (*H. K. Heseltine, J. D. Pearson*).

3. Work has continued on the infra-red spectrometer. Early in the year delivery was taken of a double beam radiation unit and some time was spent in testing and re-calibrating the apparatus. After numerous tests a comparatively simple sampling method has been found to be satisfactory for mixtures of carbon tetrachloride and ethylene dichloride in air, and it is now possible to analyse these mixtures quantitatively using the infra-red spectrometer. Slight variations in results remain, arising from the sampling technique as well as the subsequent analysis, but the error is not likely to be greater than 5 per cent even at very high concentrations and at normal fumigation concentrations it should be possible to limit the error to 1 to 2 per cent.

The method is obviously capable of extension to other mixtures of fumigants, analysis of which by normal chemical techniques is difficult. The spectrometer has also proved of use in checking the purity of certain fumigants. (*H. K. Heseltine*).

SORPTION OF FUMIGANTS BY DIFFERENT COMMODITIES

In the small scale experimental measurement of the sorption of fumigants by different grains, isotherms have been determined for the sorption of methyl bromide at 15°C by barley, oats, wheat, sorghum, unpolished rice and yellow maize. Important variations in sorption by the different grains were noted and comparisons made with data previously obtained for carbon tetrachloride. It was found that, with the exception of unpolished rice, the amounts of carbon tetrachloride and methyl bromide sorbed at comparable concentrations by a particular cereal were similar. This is unexpected, in view of the wide difference in the boiling points of the two fumigants. Unpolished rice, however, did not, with methyl bromide, show the exceptionally high sorption found with carbon tetrachloride. The work is being continued with the determination of the sorption of ethylene dichloride by the same cereals. (*S. G. Heuser, Mrs. C. E. Freeman*).

FUMIGATION OF DRIED FRUIT IN SMALL SEALED PLASTIC PACKETS

To enable advice to be given to a food manufacturer an investigation was made into the possibility of fumigating 4 oz. portions of mixed dried fruit in cellulose film packets of two types, the one heat sealed and the other sealed with adhesive. Specimen packets were made up containing, as test insects, the older pre-adult stages of *Calandra granaria* in wheat and 2–4 day old eggs of the Mediterranean Meal moth *Plodia interpunctella* and of the Fig moth *Ephestia cautella*. Several of each type of packet were exposed to methyl bromide in fumigations for 20 hours at atmospheric pressure and for 4 hours at reduced pressure (7 cm. Hg) each at two levels of concentration-time product (100 and

250 mg h per litre). At the lower c.t. product there were some survivals from the fumigation at atmospheric pressure but none in that at reduced pressure. However at the higher c.t. product complete kills were achieved at atmospheric pressure and it was concluded that fumigation at atmospheric pressure should be recommended in view of the extra expense involved in the installation of vacuum fumigation plant. The dosage rate to be used in practice has yet to be determined. (*W. Burns Brown, S. G. Heuser, Miss B. D. Hole*).

RESIDUES IN WHEAT FUMIGATED WITH ETHYLENE DIBROMIDE

The work during 1954 on the estimation of residues in wheat fumigated with ethylene dibromide has been continued with the exposure of samples of whole and ground wheat conditioned to 70 per cent relative humidity to known concentrations of fumigant in chambers at 15°, 20° and 25°C. After removal from the chamber amounts of adsorbed ethylene dibromide and also of reacted bromide were determined at intervals during the airing period. In each case, when exposed to similar concentrations and times, three to four times as much fumigant remained sorbed on the ground wheat as on the whole grain one hour after removal from the chamber, indicating very much higher total sorption on the ground material during the exposure. Total adsorbed bromide decreased with increase of exposure temperature.

Complete airing of the exposed material as determined by coincidence of total Br' content with water soluble Br' content was achieved in 21 days with ground wheat but whole grain retained some unchanged ethylene dibromide after 56 days.

Sorption measurement

Total sorption of ethylene dibromide by wheat has been more specifically determined by the method of measuring the drop in free space concentration of the gas confined over the sorbent in a glass flask. From similar gas concentrations sorption by whole wheat at 15°C was found to be approximately twice that at 25°C. (*S. G. Heuser, Mrs. G. E. Freeman*).

FUMIGATION OF WHEAT WITH ETHYLENE DIBROMIDE-CHLORO-HYDROCARBON MIXTURES

Facilities and materials were made available at the National Institute of Agricultural Engineering, Silsoe, for a test in which 17½ tons of English wheat in an experimental farm silo bin were treated with a 1:1 mixture of carbon tetrachloride and ethylene dichloride with 5 per cent ethylene dibromide added, at a dosage rate of 1 gallon per 5 tons, the bin remaining sealed for 7 days. The temperature of the grain was about 12°C during treatment. The general effectiveness of the treatment was tested by the use of cages containing the older pre-adult stages of *Calandra granaria* and tubes containing all stages except hypopi of *Tyroglyphus farinae* inserted at various depths in the grain. Gas samples were drawn from points up to 3 ft deep in the grain to determine concentrations of ethylene dibromide which is known to remain near the surface.

A very few *Calandra granaria* adults emerged from cages which had been exposed in the bottom 3 ft of grain otherwise there were no survivals and it is possible that complete kills would have been recorded everywhere had the cages been left in the grain for a longer period.

After the 7 day exposure, and at intervals during the 7 weeks period following,

samples of wheat were drawn from sites adjacent to the gas sampling points and analysed for unchanged adsorbed ethylene dibromide and for water-soluble bromide. Very little water-soluble bromide was detected but during the whole of the airing period considerable amounts of ethylene dibromide remained adsorbed on the grain particularly at points about 6 in below the surface. After 7 weeks a maximum of 124 p.p.m. total Br′ was recorded of which 109 p.p.m. (as Br′) was estimated to be adsorbed ethylene dibromide.

A sample of wheat from the surface layer containing 80 p.p.m. total Br′ was milled at the Research Association of British Flour-Millers yielding flour containing 60 p.p.m. total Br′ of which 48 p.p.m. was estimated to be adsorbed ethylene dibromide, together with bran containing 109 p.p.m. total Br′, indicating that little aeration took place during milling. This test emphasizes the extremely slow rate at which ethylene dibromide desorbs from wheat, as previously reported in laboratory scale experiments. (*S. G. Heuser, J. D. Pearson, J. B. Waller, Miss B. D. Hole, Mrs. C. E. Freeman*).

TOXICITY OF FUMIGANTS TO INSECTS

In addition to the test involving timber-boring insects and to the items of work described below considerable time has been spent in tests using mixtures of fumigants. Tests are being made to compare the toxicity of mixtures of ethylene dichloride and carbon tetrachloride with the toxicities of the separate compounds. These data are required to allow assessment of the effectiveness of treatments with the mixed fumigants in which the concentrations of each component are known. Similar tests have been made with mixtures of methyl bromide and ethylene oxide but until the programme of tests has been completed no useful assessment of the practical value of such mixtures can be made.

Some further tests of the resistance of the older pre-adult stages of *Calandra granaria* to methyl bromide have been made which show that survival increases with decrease in oxygen below about 10 per cent of the normal atmospheric concentration. Such conditions would be realized in practice in sustained vacuum fumigations at low pressures. (*Miss E. M. Reynolds, S. G. Heuser, Mrs. B. M. Reynolds, Miss M. F. East, Mrs. C. E. Freeman*).

Toxicity of hydrogen cyanide

Further tests on the toxicity of hydrogen cyanide at 25° and 15°C have been made and data have now been obtained with twelve insect species. Adults and pre-adult stages were included, making twenty-one kinds of test insect in all. These differ widely in resistance. Hydrogen cyanide is less toxic than methyl bromide to adult and pre-adult stages of *Calandra granaria* and *Calandra oryzae*, and to pre-adult stages, but not to adults, of *Rhyzopertha dominica*. Mortality of these pre-adult stages increases only very gradually with increase in c.t. product. Among the more susceptible insects were the pre-adult stages of *Callosobruchus chinensis* in lentils. These were found to be less resistant to hydrogen cyanide than to methyl bromide. The toxicity of hydrogen cyanide decreases with decrease in temperature from 25° to 15°C. (*Mrs. B. M. Reynolds, Miss M. F. East*).

Toxicity of ethylidene chloride

Tests have been made at 25° and 15°C to compare the toxicity of ethylidene chloride with ethylene dichloride and with carbon tetrachloride. Twelve kinds

of insect were tested. The general level of toxicity to these insects was comparable with that of carbon tetrachloride. The older pre-adult stages of *Calandra granaria* were the most resistant of the insects tested. These are estimated to require a c.t. product of 10 000 mg h per l. at 25° which is less than the comparable estimate of 14 000 mg h per l. obtained with carbon tetrachloride. Since small-scale laboratory tests suggest that if applied to the surface of a bulk of grain ethylidene chloride would behave similarly to carbon tetrachloride, it would appear that if commercial circumstances were favourable ethylidene chloride could be used as a fumigant for bulk grain either alone or in admixture with ethylene dichloride in substitution for carbon tetrachloride. (*Mrs. B. M. Reynolds, Miss M. F. East*).

In connexion with these toxicity tests a method of analysis was required suitable for the determination of concentrations of ethylidene chloride in gas samples taken in evacuated flasks. A number of reagents for absorbing and breaking down the fumigant were tested but none were found to give a recovery approaching 100 per cent. The most satisfactory reagent was monoethanolamine, in which the fumigant was absorbed and allowed to stand for 48 hours at controlled temperature before refluxing with dioxan and sodium. Under these conditions 50 per cent of chlorine from the molecule was recovered and good agreement obtained in replicate samples. (*S. G. Heuser, Mrs. C. E. Freeman*).

Resistance of Trogoderma granarium *to methyl bromide*

A series of tests has been completed on the effect of temperature on larval resistance from which the following estimates of c.t. products for 99·9 per cent kill have been made.

°C	*mg h per l.*
32	66
25	100
15	180
10	290

The resistance of the larvae at 10°C to methyl bromide is higher than that of any of the other stored product insects so far tested at this temperature for which an overall estimate of 200 mg h per l. for at least 99·9 per cent kill has been in use. At this lower c.t. product 98 per cent kill of *T. granarium* larvae would be expected.

The main object of this year's work on *T. granarium* has been to find out whether any modification of environment would produce larvae of increased resistance. The results so far obtained at 32°C show that resistance of larvae is increased by starvation. Tests at 25°C indicate that larvae which have become established in crevices are likely to show considerably increased resistance. The effect of prolonged exposure to low temperatures before fumigation is also being tested. (*Mrs. B. M. Reynolds*).

BIOCHEMISTRY

The work of the Biochemistry Section has progressed during the last twelve months along the lines defined and explained in the Annual Report for 1954.

There has been a number of visitors to the Section from home and overseas research centres, mainly to seek advice on radioactive tracer techniques. Dr. B. N. Smallman of the Science Service Laboratory, London, Ontario, completed

his experimental studies in the Section during the year. Joint publication of this work is in preparation.

Advice and practical aid have been given, by request, to several research organizations employing radioisotope techniques. This has taken the form of demonstrations of radioassay techniques, supervision of preliminary experiments in connexion with a plant tagging experiment by the National Institute of Agricultural Botany and a mixing experiment by the British Baking Industries Research Association. Assistance was also given to the Dunn Nutritional Laboratory in the design and operation of special counters for low carbon-14 activities.

The experimental work has been summarized under three main headings, as in previous reports, as follows:

Studies on the Nature and Significance of Insecticide Residues in Foodstuffs

NATURE AND SIGNIFICANCE OF ETHYLENE DIBROMIDE RESIDUES IN FUMIGATED WHEAT.

The studies made under this heading have been completed during the year and a paper submitted for publication.

Bromine-82 labelled ethylene dibromide has been used to study its absorption and decomposition in wheat under conditions of fumigation and on subsequent airing and heating. In spite of the high physical sorption of the fumigant and its slow rate of airing the amount of chemical reaction between it and the wheat is small at room temperatures. On heating imperfectly aired, fumigated wheat at temperatures similar to those used in baking, about one third of the residual ethylene dibromide undergoes decomposition to ethylene glycol, the remainder volatilizing. There is some evidence that the glycol so formed reacts with the $-SCH_3$ group of the protein methionine of the wheat.

The high sorption of ethylene dibromide by wheat combined with the slow rate of airing, present the principal toxic hazard in its use as a cereal fumigant on account of the toxic nature of ethylene dibromide itself. This hazard may be minimized by efficient airing both before and after milling.

As ethylene glycol is considerably less toxic than ethylene dibromide, heating, e.g. baking, very materially reduces any hazard presented by chemical residues in the final product. (*R. G. Bridges*).

GAMMA-BENZENE HEXACHLORIDE RESIDUES IN FOODSTUFFS

A study of the magnitude and nature of gamma-benzene hexachloride residues likely to occur when cheese and wheat are treated with the insecticide under practical conditions has been commenced. For this purpose methods for the preparation and separation of the carbon-14 labelled isomers have been successfully developed. (See p. 48.) (*R. G. Bridges*).

Studies on Mechanism of Insecticidal Action

EFFECTS OF INSECTICIDES ON THE PHOSPHORUS METABOLISM OF THE ADULT HOUSEFLY

A great deal of attention has been paid to the effects of DDT on the phosphorus metabolism of the intact adult housefly (*Musca domestica*), by the methods indicated in earlier reports (1952 *et seq.*) and in published papers. The

behaviour of DDT-poisoned insects indicates clearly some profound neuro-muscular disturbance which has been explained on the basis of facilitated synaptic transmission. There is some evidence, however, that the great neuro-muscular activity of the poisoned insect does not account for its death. It has now been found that DDT causes a slow but marked depletion of the vital substance adenosine triphosphate (ATP). This depletion would certainly account for the later prostration observed in poisoned insects and, if sustained would account for its ultimate death. The reduction in ATP has been observed in the head tissues 5 h after DDT treatment, but after 10 h or longer an equally marked reduction of thoracic ATP has been observed. The fall in ATP occurs when the insect's respiration is still at a high level. It also occurs when the insect has been spared any intense muscular exhaustion by sustained anaesthesia. These results suggest that DDT "uncouples" tissue oxidation and ATP synthesis in the intact insect despite the fact that other workers have failed to demonstrate this *in vitro*; they further suggest that the ATP depletion is not simply a consequence of the neuro-muscular disturbances.

The level of ATP did not fall in DDT-resistant flies which had received the same dose of DDT. If the fall in ATP is a direct biochemical lesion in susceptible flies, and the evidence to date points to this, it suggests that resistance may involve biochemical factors other than an enzymic detoxication mechanism. (*F. P. W. Winteringham*, *G. C. Hellyer*, *A. Weatherley*).

EFFECTS OF INSECTICIDES ON THE METABOLISM OF ^{14}C-LABELLED ACETATE BY THE ADULT HOUSEFLY

The success of the "labelled phosphorus pool" technique for studying the effects of insecticides on phosphorus metabolism *in vivo* prompted its extension to non-phosphorus containing metabolites. This was achieved by injecting houseflies with ^{14}C-labelled acetate when certain amino acids and other substances became labelled. The labelled compounds were then extracted, resolved by paper chromatography, and assayed quantitatively by the 2-π and 4-π scanning techniques already developed. By repeating such experiments with poisoned insects disturbances in basal metabolic processes have been followed quantitatively. Some very interesting data have been obtained in this way. For example, following the injection of radio-active acetate, free glutamic acid, proline and glutamine rapidly became labelled and the former two were apparently in rapid exchange with the same amino acids of the tissue protein. Only traces of the injected radioactive carbon were found in the free alanine and aspartic acid fractions. This could be explained by a profound difference between the respiratory metabolism of insects and vertebrates. As was to be expected a proportion of the injected radioactive carbon appeared as carbon dioxide. Provision was therefore made for automatically and continuously recording the oxygen consumption of the experimental insects and for collecting and assaying the expired carbon dioxide and its radioactivity.

A very small proportion of the injected radioactive carbon was found to be incorporated into a compound which could not be resolved from added acetylcholine by paper chromatography. This provides further independent evidence for the presence of acetylcholine in the thoracic and head tissues of the adult housefly. It was further possible to detect the labelled acetylcholine with a sensitivity and specificity several times greater than conventional pharmacological techniques.

Preliminary experiments using these techniques have demonstrated an accumulation of acetylcholine within 30 min of applying di*iso*propyl phosphorofluoridate (DPF) to houseflies. This provides evidence, for the first time, of anticholinesterase action in insects in terms of acetylcholine as distinct from inhibition of the esterase. After 2 h the acetylcholine level had fallen to that of the untreated control insects. A further effect of DPF poisoning was the accumulation of free glutamine at the expense of free glutamic acid, this possibly being associated with the observed DPF-induced convulsions.

These techniques and the results being obtained thereby are likely to be of interest and possibly of importance, to other workers in the field of drug action generally. (*F. P. W. Winteringham, A. Harrison, Mrs. S. Drysdale, Miss A. Weatherley*).

METABOLISM OF ^{14}C-LABELLED ALLETHRIN BY THE ADULT HOUSEFLY

Studies of the metabolism of ^{14}C labelled allethrin by *Musca domestica* adults *in vitro* and *in vivo* have been continued. (See published papers, p. 58.)

Samples of lipase-active powder prepared from *Musca domestica* adults were incubated with ^{14}C-labelled allethrin in phosphate buffer at 37°C under continuous agitation. After a "metabolism" period incubates were extracted with ether and the extracts examined by paper chromatography; the relative proportions of the ^{14}C activity behaving as unchanged allethrin and as metabolites or decomposition products were thus determined. Results indicated that hydrolysis of ^{14}C-labelled allethrin by lipase powder was less than 8 per cent after 24 hours incubation.

Adult female *Musca domestica* were injected intrathoracically with a solution of ^{14}C-labelled allethrin in acetone, and after a "metabolism" period at 30°C flies were homogenized with ethanol and the ethanol extracts examined chromatographically as in the *in vitro* experiments. Results showed that 50 per cent of a dose of 4·0 μg ^{14}C-labelled allethrin per fly was hydrolysed during a metabolism period of 24 h. A brief exposure to methyl bromide before injection, and from which flies appeared to recover fully, reduced the amount of hydrolysis by 50 per cent. A brief exposure to hydrogen cyanide, from which flies did not recover before injection, completely inhibited the hydrolysis of allethrin. A practical objective of this work is to understand better the mechanism by which allethrin might be synergized more effectively than by piperonyl cyclonene etc. Classical inhibitors such as cyanide and thiol reagents (methyl bromide) were used to gain some idea of the nature of the *in vivo* enzymic mechanisms of detoxication. The ^{14}C-labelled allethrin is also being used to obtain further data on the absorption of the insecticide through the insect cuticle, and the effects of various adjuvants on this. (*Mrs. P. M. Bridges*).

AEROBIC METABOLISM IN INSECT MUSCLE: *IN VITRO* STUDIES

The study of the metabolism of sarcosomes isolated from the flight muscle of the blowfly *Calliphora erythrocephala* has been continued, particularly in relation to the succinic oxidase system. The substance responsible for the limitation of succinate oxidation has been identified as oxaloacetate by examination of the 2-4-dinitrophenylhydrazone.

Further experiments on the stimulation of succinate and malate oxidation by Mn^{++} suggested that the sarcosome preparations may contain a malic enzyme similar to that found in vertebrate liver and in plants. This enzyme

catalyses the oxidative decarboxylation of malate to pyruvate in the presence of Mn^{++} and coenzyme II. Further evidence was obtained with an aqueous extract of an acetone dried powder prepared from blowfly thoraces. This preparation catalysed the reduction of coenzyme II in the presence of malate, and a reversal of this reaction was observed when pyruvate and CO_2 were added to the system. Since the addition of pyruvate alone resulted in some reoxidation of reduced coenzyme II the presence of lactic dehydrogenase was indicated. The fact that reduced coenzyme I was also oxidized in the presence of pyruvate provides further evidence of lactic dehydrogenase activity. The latter observation is particularly interesting in view of a recent report in the literature that lactic dehydrogenase is not present in the muscle of the housefly *Musca domestica*. A report of this work has been submitted for publication.

Inhibition of the succinic oxidase system by malonate

When studying the phosphorylation associated with the oxidation of α-ketoglutarate to succinate, malonate is usually added to prevent the oxidation of succinate. While investigating these reactions in insect sarcosomes it was observed that the amount of oxygen consumed was greater than could be accounted for by the oxidation of α-ketoglutarate to succinate. Such an effect would be obtained if malonate failed to inhibit succinate oxidation. Before carrying out further studies on the oxidative phosphorylation reactions, the action of malonate on the succinic oxidase system is being investigated. The possibility that malonate was being metabolized by the insect sarcosomes was examined, but no evidence of oxidation or decarboxylation has been obtained. (*S. E. Lewis*, *G. M. Price*, *K. H. Hallowes*).

ACETYLCHOLINE IN INSECTS

Identity of the acetylcholine-like substance in insect tissue

Chromatographic evidence considered together with the known pharmacodynamic properties of extracts from insect tissue now argue strongly in favour of the identity of the active substance with acetylcholine.

Further experiments with blowfly heads have shown that anomalies previously observed when extracts were chromatographed in a neutral solvent were due to interference by trichloracetate, even though free trichloracetic acid had been removed. When an extract is prepared from a homogenate in hydrochloric acid, however, and chromatograms are run in a butanol/water solvent, sections of the strip being assayed on the frog muscle preparation, it is seen that the activity of the extract runs parallel to acetylcholine chloride and is not separated from it when the latter is co-chromatographed with the extract.

Actual isolation of the active substance has not been further attempted in view of the amounts obtainable (an extract of 1000 fly heads shows activity of the order of 0·1 mg acetylcholine equivalent), but confirmatory tests are being carried out on preparations from the heads of some 8000 flies. The possibility of the presence of other substances which may be of significance in insect nerve mechanisms is being further examined in view of recent reports that such substances are present in the head of the honey-bee.

Synthesis of acetylcholine in vitro: *effect of diet and age of flies*

In investigating the synthesis of acetylcholine in homogenates of whole flies, in the presence of an anticholinesterase (eserine), it has been found that the

capacity for synthesis depends markedly on the age of the flies and on the diet of the adults. For example in homogenates from blowflies fed on sucrose and water, while the initial rate of synthesis seems to be largely independent of age, the ability to maintain a steady rate increases with age up to 21–28 days. Again with 28-day old blowflies fed on liver in addition to sucrose and water the initial rate of synthesis is more rapid and is maintained until a much higher level of acetylcholine has been reached than is the case with flies of similar age fed on sucrose and water only.

The significance of these findings will have a bearing on the interpretation of some earlier figures for acetylcholine levels in insects obtained by other workers under conditions which did not preclude synthesis in the homogenate. (*K. S. Fowler, S. E. Lewis*).

Estimation of acetylcholine in insects

In order to determine the acetylcholine content of insects various methods of extraction have been examined. For this purpose the head of the blowfly, *Calliphora erythrocephala*, has been used, and the acetylcholine content of the extracts has been estimated by means of a frog muscle preparation. The particularly high cholinesterase and choline acetylase activity found in some tissues has emphasized the importance of inhibiting both these systems before extraction of the acetylcholine is attempted. This work has also demonstrated, in insect tissue, the increase in mutual availability of acetylcholine and cholinesterase which occurs when tissue is frozen. As a result of this effect of freezing, it was not possible to obtain the maximum yield of acetylcholine from frozen tissue, even when the latter was ground under liquid nitrogen in the presence of 10 per cent trichloracetic acid. The method finally adopted was to plunge the tissue into boiling Ringer solution brought to pH3, and to extract the homogenized tissue in the presence of 1 per cent trichloracetic acid, since this procedure gave the highest yield under conditions where synthesis of acetylcholine was prevented.

Mean values for the acetylcholine content of the heads of various insects, and of the isolated thoracic nerve cord of the cockroach, *Periplaneta americana*, are given below:

Calliphora erythrocephala	32·7 μg/g
Lucilia sericata	28·3 μg/g
Musca domestica	26·1 μg/g
Tenebrio molitor	7·8 μg/g
Periplaneta americana	9·8 μg/g
Periplaneta americana (Nerve cord)	36·7 μg/g

This method is now being employed to study the effect of insecticides on the acetylcholine content of *Calliphora*. Preliminary experiments with flies poisoned with DDT showed no change in the acetylcholine content of whole flies at 30 min or at 3 h after treatment with the insecticide.

When di-*iso*propyl phosphorofluoridate (DPF) was applied to the thorax the acetylcholine content of the head increased by about 20 per cent within 15 min (cf. also the work with (^{14}C) acetate).

The work on the methods of extraction was carried out in collaboration with Dr. B. N. Smallman, and has been prepared for publication. (*S. E. Lewis, K. H. Hallowes*).

Miscellaneous work

PREPARATION OF ^{14}C-LABELLED BENZENE HEXACHLORIDE ISOMERS

The preparation and separation of the carbon-14 labelled benzene hexachloride isomers have been carried out in collaboration with Dr. D. F. Heath of the Toxicology Unit of the Medical Research Council. A mixture of the isomers containing approximately 25 per cent of the gamma-isomer was prepared by chlorinating carbon-14 labelled benzene under controlled conditions at this Laboratory. The gamma-isomer was separated by chromatography on a column of silicic acid by Dr. Heath. (*R. G. Bridges*, *A. Harrison*).

SEPARATION OF BENZENE HEXACHLORIDE ISOMERS BY REVERSED-PHASE PAPER CHROMATOGRAPHY

The alpha, beta, gamma, and delta isomers of benzene hexachloride have been separated on paper chromatograms by applying a solution of a mixture of the isomers to a strip of Whatman No. 1 filter paper treated with a 5 per cent solution (w/v) of Paraffinum Molle Album in ether to provide the stationary phase. The strip was then chromatographed in the normal manner using a mobile phase consisting of 70 per cent methanol and 30 per cent water by volume. The position of the isomers on the dried chromatogram could be detected as brown spots by dipping the strip in monoethanolamine, heating at 100°C for ½ h, redipping in 0·1N aqueous silver nitrate solution acidified with nitric acid and exposing to ultra violet light. The alpha, beta, gamma, and delta isomers moved with mean R_f values of 0·33, 0·00, 0·40 and 0·58 respectively. (*R. G. Bridges*, *A. Harrison*, *F. P. W. Winteringham*).

SECOND 4-π COUNTER FOR SCANNING SOFT BETA EMITTERS SEPARATED ON PAPER CHROMATOGRAMS

The extension of the "labelled pool" studies to ^{14}C-labelled acetate metabolism in insects and the assay of trace substances such as ^{14}C-labelled acetylcholine particularly, greatly increased the demands on the 4-π scanning techniques developed earlier. A second 4-π counter (Mark II) of modified and simpler design was therefore constructed and is now in regular use. The Mark II counter has a sensitivity to carbon-14 comparable with that of the original model but does not have facilities for separately scanning both sides of the paper chromatogram or for the reduction of the effective background counting rate by anticoincidence circuitry. In the Mark II model the paper is fed at right angles to the anode wires instead of the same direction as in the Mark I. This has permitted a reduction in the projected area and, therefore, in the background counting rate of the sensitive volume. (*F. P. W. Winteringham*, *A. Harrison*, *Mrs. S. Drysdale*, *M. A. Cordaroy*).

ELECTROLYTIC RESPIROMETER FOR INSECTS

Capraro has briefly described an electrolytic technique for measuring the oxygen consumption of small mammals (*Nature*, 1953, **172**, 815). This suggested the development of a similar technique for insects which has now been used in the "labelled pool" studies with considerable success. The insects are confined in a small glass "metabolism chamber" containing an alkali well for absorbing expired carbon dioxide. The chamber is connected to a closed tube containing a series of graded "Nichrome" electrodes at different positive potentials. As the

expired carbon dioxide is absorbed within the chamber the oxygen inspired by the insects causes a slight reduction in pressure and this sucks alkali into the tube on to one or more of the electrodes and so generates oxygen electrolytically according to the demand. The current flowing through the electrolytic unit is recorded automatically and continuously and since it is strictly proportional to the weight of oxygen generated it is a measure of the oxygen demand. The entire apparatus is enclosed in a constant temperature cabinet.

COLONIAL LIAISON

During the year correspondence with Colonial territories has again raised many interesting problems of food storage. In 1955, 1016 letters were received on Colonial matters, and 1147 were sent out. Also discussions were held at the Laboratory with 70 visitors from the Colonies and 34 from the United Kingdom.

The realization that many of the Colonial problems can often only be finally solved by investigations in the territories has resulted in the agreement by the Colonial Office to form a Pool of Stored Product Workers at the Laboratory. The existence of this Pool will enable a territory to have the services of a specialist to investigate a problem locally over a period of probably not exceeding 2 years. On completion of the investigation, the specialist would return to the U.K. and the territory would have no further financial commitment. It is intended to have a Pool of four officers in the first instance, and it is probable that the first members will be trained and ready to take up their appointments by October 1956.

The establishment of a Tropical Stored Product Research Unit within the Regional Research Centre at the Imperial College of Tropical Agriculture in Trinidad has been approved. The research worker appointed will work closely with the Department of Entomology of the College and with the Pest Infestation Laboratory.

A few territories have decided to appoint officers for stored products research and these appointments have been filled from Colonial studentships. The students, who are entomologists, attend at the Field Station of the Imperial College of Science and Technology for a long period of research training. This is followed by several weeks instruction on inspection and control work at the Ministry of Agriculture, Fisheries and Food, and special instruction on practical and research aspects of Colonial problems at the Pest Infestation Laboratory. During 1955 special courses of instruction were given to Mr. J. R. Cutler before joining the West African Stored Products Research Unit, and to Mr. J. C. Davies before taking up an appointment as stored product entomologist to the Department of Agriculture, Uganda.

Two Food Storage Courses for Produce and Storage officers etc. from Colonial territories have been given by the Ministry of Agriculture, Fisheries and Food in 1955. The territories which have sent officers to this Course are Aden, Brunei, Cyprus, Gold Coast, Jamaica, Kenya, Nigeria, Sierra Leone, Tanganyika and Uganda. The Ministry has also provided special courses on fumigation for six officers from Tanganyika and Kenya, and on storage problems to three other officers, two of whom are concerned with Public Health. A special programme including discussions at the Laboratory was arranged with other Government Departments and private firms for a number of officers, including, Mr. I. Forsyth, Gold Coast entomologist, Mr. J. C. Duerden, West African Stored

Product Research Unit entomologist, and Mr. L. D. Cleare, Assistant Director of Agriculture in British Guiana.

The Assistant Colonial Liaison Officer, Mr. G. A. Haswell, was on tour in East, Central, and South Africa from October until December 1955.

ADVISORY WORK

The problems on which advice has been sought are many and varied, and only a few of the major problems are given below.

Many territories are concerned with the storage of famine reserves of grain for which underground storage in pits is recommended. Information on this method of storage is being sought by an increasing number of authorities. In collaboration with the D.S.I.R. Building Research Station, plans for a new design of pit have been approved.

Preliminary results on a few of the types of gas proof sheeting material being tested (1954 report) are available. Under the practical conditions pertaining in Nigeria, neoprene-coated cotton and polyvinyl chloride-coated nylon have not proved suitable. A new type of sheeting which incorporates polythene is being tried, in addition to others mentioned in the 1954 Report.

The fumigation of produce with methyl bromide under gas proof sheets is being used on the Laboratory's advice in a number of Colonial territories especially in Africa. The success of this method of disinfestation has been well proved in the U.K. and information from a number of sources indicates that this is generally true under tropical conditions.

There is a growing appreciation in many Colonies of the need to disinfest foodstuffs prior to export, and several enquiries have been received, e.g. from Kenya, Nigeria, and the Gold Coast, on the construction of chambers to be erected at Mombasa, Apapa, and Tema respectively. Such chambers can, of course, also be used for the treatment of commodities entering the territories.

Advice has also been given to Government departments in a number of territories about grain storage schemes. This advice which includes information on types of storage structures, takes cognisance of the local economic agricultural and marketing conditions.

REPORTS

The following reports and papers have been prepared:

- (a) Stored Product problems in British Guiana
- (b) Report on Food Storage in Gold Coast
- (c) Report on Food Storage in Antigua
- (d) Report on Food Storage in East Africa (Abridged version)
- (e) The Underground Storage of Grain
- (f) Quality of Gambian Groundnuts 1954/55 crop
- (g) The Groundnut Bruchid (*Caryedon fuscus*)
- (h) Further Observations on the Methods used for Estimating Insect Fragment Contamination of Maize Meal.

SUMMARY OF MAJOR DEVELOPMENTS IN COLONIAL TERRITORIES

(a) *Kenya*

The Maize Control organization are undertaking to fumigate stacks of product under gas proof sheets with methyl bromide and are having a number

of officers trained in this disinfestation method (p. 49). Maize is now being fumigated with methyl bromide at up-country depots and at the port of Mombasa.

Survival of *Tribolium castaneum* in stacks of maize fumigated under sheets with methyl bromide has been reported. This is being investigated.

Following experimental work in Kenya, the practice of dusting maize cobs stored in farm cribs with 0·5 per cent gamma benzene hexachloride dust is now recommended. According to a recent report, the weevil *Calandra oryzae* is now a rare insect in cribs and stores.

Two private firms are considering the erection of fumigation chambers at Mombasa, where fumigation facilities are at present extremely limited.

(b) *Uganda*

A stored product entomologist is being appointed to the Department of Agriculture and will take up his duties in April 1956.

A Grain Conditioning and Storage Board is now responsible for the marketing and storage of maize in Uganda, and it is considering plans for increased storage facilities of the best type.

A Standardization Sub-Committee of the Kampala Produce Exchange is discussing the formulation of quality standards for produce.

Two experiments with damp grain stored in the small pits of the Tanganyika Department of Grain Storage are being carried out for Uganda.

(c) *Tanganyika*

Much of the fumigation of foodstocks in the territory is now undertaken by a commercial company.

Two of the 120 ton experimental pits belonging to the Department of Grain Storage have been filled with damp grain. The Moshi pit was filled with Uganda maize of very variable moisture content averaging about 16·6 per cent. Grain condition remained good for at least 83 days but a deterioration in colour and a decrease in germination was noted 104 days after sealing. Palatability tests carried out after about 118 days of storage indicated that the meal had a distinctly alcoholic smell and was only fairly satisfactory as food. The experiment was therefore brought to an end. The maize taken from the pit after airing and admixture with ordinary maize produced a palatable meal.

The Morogoro pit was filled with Uganda maize of average moisture content 14·8 per cent. After 29 days of storage (sealed 3/12/54) a persistent alcoholic smell was noted. The general appearance of the grain remained good and palatability tests indicated a favourable comparison with normal meal. The experiment continues.

The Department of Grain Storage is building a number of large commercial scale pits, each of about 410 tons capacity, to provide a total of 8000 tons storage capacity.

(d) *Northern Rhodesia*

The Maize Control Board have erected two concrete silos, one each at Lusaka and Monze, and are proceeding to build a third at Kitwe. The bins are of conventional design made of concrete. A recommendation was made to have all bins piped to enable disinfestation to be carried out with methyl bromide by circulatory fumigation. A recent sudden outbreak of *Trogoderma granarium*

in maize stocks has indicated the need for this type of equipment in these silos. A Colonial Office research worker, Dr. K. F. Salmond, is working for the Maize Control Board on grain storage problems.

The Maize Control Board has purchased sheeting and equipment to enable a number of stacks of produce to be fumigated with methyl bromide. This has been carried out by a fumigating company during short visits to the Territory.

(e) *Southern Rhodesia*

The Grain Marketing Board's large new silo at Salisbury which has every bin fitted for circulatory fumigation (1954 Report) is now in use. The efficiency of the circulatory system, on which this Laboratory gave advice, has been checked by experiments carried out on the silo by Mr. W. Burns Brown and Mr. H. K. Heseltine. (See above).

(f) *Nyasaland*

In a second experiment on underground storage carried out in the pit at Zomba, maize of 10·8 per cent moisture content (range 9·3 per cent to 14·7 per cent) has been stored successfully over a period of 862 days under the existing conditions. A report on the two pit experiments in Nyasaland has been prepared by Dr. K. F. Salmond, who is now in N. Rhodesia.

(g) *Nigeria*

The West African Stored Products Research Unit (W.A.S.P.R.U.) is now organized on a Nigerian basis, its funds being derived from the Government of Nigeria and the Nigerian Produce Marketing Boards. The staff of four Scientific Officers is being increased eventually to eight. This will enable the Unit to work on problems arising in the fields of local foodstuffs, palm oil, and grain storage.

A programme of research on methods of grain drying and storage is being undertaken jointly by the University College and W.A.S.P.R.U. at Ibadan.

The suitability of underground storage is being considered by the Northern Region Department of Agriculture.

The rolling stock position has improved with a consequent considerable reduction in the number of groundnut pyramids at Kano and out stations.

(h) *Gold Coast*

A small experimental pit of 45 ton capacity has been built at Kwadaso, in which concrete slabs have been used as the roof. The Department of Agriculture are carrying out tests on this pit.

A survey of farmer's crib storage of maize has been carried out which has given some interesting figures.

The importance of insect infestation (especially *Lasioderma serricorne* and other beetles) on cocoa has assumed prominence.

(i) *Sierra Leone*

A research entomologist, Mr. P. Prevett, has taken up an appointment with the Government to investigate rice storage problems.

The Pest Control Officer of the Department of Commerce and Industries has attended a special course of instruction in the U.K.

(j) *Gambia*

The Groundnut Marketing Board has decided to export the whole of the groundnut crop as decorticated nuts and has installed a few large decorticating plants.

Experiments carried out in the Gambia have shown that the beetle *Caryedon fuscus* can be controlled easily and that mounds of undecorticated nuts can be protected (p. 24). Experiments have also shown that control of *Tribolium castaneum* in the decorticated nuts is not an easy problem.

(k) *Trinidad*

Approval has been given for the appointment to the Imperial College of Tropical Agriculture, within the Regional Research Centre of the Caribbean, of a stored products specialist. It is intended that this Tropical Storage Research Unit would work in close collaboration with the Pest Infestation Laboratory.

(l) *St. Lucia*

The work now being organized on storage problems will be co-ordinated and progress will be reviewed by a Committee which is being set up.

(m) *British Honduras*

Losses from *Calandra oryzae* during crib storage of maize with the sheath on has been reduced by about 20 per cent by storing the cob maize without the sheath and dusting with lindane. (See above, under Kenya).

(n) *Cyprus*

Approximately 10 000 tons of barley will be stored in a number of pits, each of capacity 900 tons. These pits of new design incorporate the Ctesiphon form of roofing, and are being constructed at the present time.

(o) *Aden*

A plywood silo of the type referred to on p. 44 of the 1954 Report has been ordered by the Protectorate for experimental purposes in the Eastern Province.

(p) *Malaya*

A committee has been formed to conduct experiments on storage: The suitability of underground storage and storage in above ground concrete and plywood silos for rice is being considered.

(q) *Singapore*

Small pilot schemes have been started to ascertain the best method of storage for rice. Experimental work involving under-ground storage and above-ground silo storage using different mechanisms for controlling insect infestation is being considered.

EXPERIMENTAL WORK

A considerable amount of experimental work is being carried out in the Laboratory which has a direct or indirect bearing on Colonial problems. Details of the major items of work are given under the appropriate Section concerned and only brief references are made to these items here. The topics listed below include these and also *ad hoc* problems which have been or are being investigated.

Water vapour barriers for floors of storage premises

The original plan (1954 Report) was to terminate this test after a period of 6–9 months. After 14 months there was an increase in moisture content of only one per cent of the wheat in contact with some of the treatments and with the control. Only very limited conclusions could be drawn but in consultation with the Road Research Laboratory it has been decided to modify the experiment and continue tests for a further period. (*T. A. Oxley*, *D. W. Hall*, *Miss P. M. Davey*).

Effect of insect attack on acidity of maize

Samples of South African white flat dent maize were subjected to infestation of 200 adult *Tribolium castaneum* for 3 months. The oil content, fat acidity, phosphate acidity, amino-acid acidity, and water soluble acidity of this maize were determined by the Colonial Products Laboratory. The fat, phosphate and water-soluble acidities had increased, the amino-acid acidity had not and the oil content had decreased. This work is being repeated and further investigations are being carried out. (*D. W. Hall*, *Miss P. M. Davey*).

"*Filth test*"

The Government Chemists of Tanganyika, Uganda, Kenya, Nigeria, Trinidad, and Northern Rhodesia have been informed of the results of the collaborative work on the examination of maize meal for insect fragments and rodent hairs referred to in the 1953 and 1954 Reports. Their co-operation in making tests on the procedure developed by the Colonial Products Laboratory has been sought. (*D. W. Hall*).

Effect of insect attack on acidity of groundnuts

A supply of good quality decorticated groundnuts of one variety have now been obtained from Nigeria. These have been hand sorted and the experiments mentioned in the 1954 Report are in progress. This work is being carried out in collaboration with the Colonial Products Laboratory who will be doing the chemical analyses. (*D. W. Hall*, *Miss P. M. Davey*).

Characteristic damage to groundnuts caused by several insect pests

When examining samples of groundnuts from West Africa it became obvious that there were signs of damage by insects other than those seen living or dead in the sample. Experiments have been carried out using decorticated and undecorticated groundnuts to obtain information on the types of damage caused by the following insect species, *Corcyra cephalonica*, *Plodia interpunctella*, *Ephestia kühniella*, *Caryedon fuscus*, *Laemophloeus ferrugineus*, *Necrobia rufipes*, *Oryzaephilus mercator*, *Tenebroides mauritanicus*, *Tribolium castaneum*, *Tribolium confusum*, *Trogoderma granarium*. (*D. W. Hall*, *Miss E. Cawthra*, *Miss P. M. Davey*).

Bruchids (*Bean weevils*)

A survey of the literature on the world distribution and biology of three Bruchids of economic importance to stored pulses has indicated the following general conclusions:

Callosobruchus quadrimaculatus is a New World species which has now spread throughout the tropics and sub-tropics wherever cowpeas are grown.

C. analis is an Old World species now occurring on peas and beans only in the warm regions of that part of the world.

C. chinensis breeds in many different legumes and has spread over the world from its Asiatic origin.

All three species have optimum development at 30°C but only *C. chinensis* can overwinter in countries where temperatures drop to near freezing. (*Miss P. M. Davey*).

Tests on paper, or paper-lined sacks

Multi-walled paper sacks or paper-lined jute sacks provide a mechanical barrier to the passage through them of certain species of insects (1954 Report).

At the request of the West African Stored Products Research Unit the penetration of methyl bromide into multi-walled paper sacks was tested. This showed that high concentrations of the fumigant were obtained inside all the sacks tested.

Field experiments with paper lined jute sacks filled with decorticated groundnuts and with cocoa have been organized.

The experiment with decorticated groundnuts was carried out in the Gambia where the sacks were stored for 4 months prior to shipment. The type of paper liner used absorbed a considerable amount of oil and was in a poor condition at the end of the experiment. (See p. 26).

The experiment with cocoa is being carried out in the Gold Coast with the co-operation of the senior specialist of the Department of Agriculture. (*D. W. Hall*).

Susceptibility of nutmegs to attack by insects

Nutmegs in three conditions were used:

1. Undamaged and unshelled
2. Damaged and unshelled
3. Undamaged and shelled

The damaged unshelled nutmegs had a 2 mm diameter hole at one end of the shell which results from the nutmeg being picked from the tree before it is ripe. These are commonly called "*Casse têtes*".

The three forms of nutmegs were exposed to attack by a number of species of insects at 30°C and 70 per cent relative humidity. Type 1 nutmeg had the shell superficially gnawed but not penetrated by the Cacao weevil *Araecerus fasciculatus*. It was immune from penetration by the other species used in the experiment.

Types 2 and 3 nutmegs were readily attacked by *A. fasciculatus* and *Tribolium castaneum*.

Carpophilus dimidiatus, *Oryzaephilus surinamensis* and *Ephestia cautella* attacked the nutmegs but could not maintain an infestation. The larvae of *Lasioderma serricorne* did not cause damage. (*D. W. Hall, Miss P. M. Davey, Miss J. E. Currie*).

Thermocouple spear for measuring temperatures in bag stacks

This spear has been tested in the field for ease of penetration into the middle of large stacks of bagged grain. Six spears are being manufactured for testing in a number of Colonial territories. (*G. A. Haswell, D. W. Hall*).

Field apparatus for measuring concentrations of carbon dioxide and oxygen

The increasing use of underground storage in Colonial territories has precipitated the need for an apparatus which can check the efficiency of each pit by measuring, on the spot, the carbon dioxide and oxygen concentrations of the intergranular air. A field apparatus which was thought to be suitable for this purpose was suggested by Mr. W. Burns Brown.

The accuracy of this instrument was checked against a catharometer reading to 0·1–0·2 per cent. When the instrument was used according to the specification of the manufacturers the analyses agreed to $\pm$ 0·4 per cent at concentrations of 13·0 per cent, 7·0 per cent, and 2·0 per cent carbon dioxide. Similar analyses are being carried out with oxygen in collaboration with the Grain Storage Section. (*D. W. Hall, Miss P. M. Davey, G. A. Haswell*).

The suitability of the Coal Board Gas Sampling Pump for use in conjunction with this apparatus has been tested. Provided all parts of the sampling pump are well flushed out this method can be used. (*D. W. Hall, G. A. Haswell*).

G. V. B. HERFORD,
Director.

PEST INFESTATION RESEARCH LABORATORY,
London Road,
Slough, Bucks.

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APPENDIX I

Papers Published in 1955

1. BRIDGES, R. G. The Fate of Labelled Insecticide Residues in Food Products. III. *N*.-Methylation as a Result of fumigating Wheat with Methyl Bromide. *J. Sci. Fd Agric.*, 1955, **6** (5), 261–268.
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APPENDIX II

Staff of the Pest Infestation Laboratory, 31st December, 1955

Director of Pest Infestation Research: G. V. B. Herford, O.B.E., M.Sc., M.Inst.Biol.

Assistant Director: E. A. Parkin, D.Sc., Ph.D., M.Sc., D.I.C., M.Inst.Biol.

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Assistants (Scientific): Miss M. Keeping, Miss G. Wickenden.

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14 Industrial Staff

* On National Service
† Treasury Bursar

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